BLUE HILL METEOROLOGICAL OBSERVATORY.
EXPLORATION OF THE AIR BY MEANS OF KITES.

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EXPLORATION OF THE AIR

BY MEANS OF KITES.

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APPENDIX B.

EXPLORATION OF THE AIR BY MEANS OF KITES.

I. — Kites and Instruments.

By S. P. Fergusson.

Kites were employed in scientific studies by Alexander Wilson of Scotland, who sent up a thermometer on a kite in 1749, and by Benjamin Franklin, about three years later, in his well known electrical experiments.

Systematic explorations of the air by kites carrying instruments have been attempted only in recent years. One of the earliest of these investigations was undertaken in England by Mr. Douglas Archibald in 1883, the object being to ascertain the rate of increase of wind velocity with increase of altitude. The instruments carried by the kites were small Biram anemometers, indicating by means of dials the total movement of the air from the time the instruments left the ground until their return.

At Blue Hill Observatory kites were used in making observations of atmospheric electricity by Mr. Alexander McAdie during the summer of 1885, and again in June and July, 1891, and July and August, 1892. (Harvard Annals, Vol. XL. Parts I. and II.) The kites employed were tailed kites of the ordinary hexagon pattern, and were coated with tin-foil, which served as a collector of the electricity that passed down a copper wire to the electrometer at the ground. No high flights were attempted.

In July and August, 1894, Mr. William A. Eddy of New York, who had been very successful in reaching great altitudes with kites designed by himself, spent two weeks at the Observatory for the purpose of elevating instruments with his kites. After a few days of experiment, it was proved that the Eddy kites could raise self-recording instruments; and on August 3, an ordinary Richard thermograph was altered for use in the experiments. The parts usually made of iron and brass were replaced by others made of hard rubber and aluminium, and the modified instrument, including a basket inverted over it to screen the bulb, weighed 1.1 kilograms. On August 4, 1894, this instrument was raised 436 meters (the height being

determined from angles observed at two stations 100 meters apart), and an excellent record of temperature was obtained. Five Eddy kites, having a total area of nine square meters, were employed. This experiment was repeated successfully on August 15, and a detailed account of both flights, prepared by Mr. Clayton, was published in the American Meteorological Journal for December, 1894; details of the kites and instrument were also published in the Scientific American for September 15, 1894. It is believed that these are the first instances of the elevation of self-recording instruments by kites. Self-recording instruments are those which record their indications graphically and continuously on paper, with ink or otherwise, in such a manner that the records may be preserved. This definition is given in order to distinguish such instruments from simple indicating or registering instruments provided with dials or scales only, and from which the indications are obtained by means of direct eye readings. The great superiority of a continuous record to eye observations even at frequent intervals has long been recognized, but until recently self-recording instruments have not been made sufficiently light to be suitable for use with kites. Prior to 1894, thermometers had been raised to heights of about 500 meters, and kites alone had been flown as high as 1,700 meters, indicating that light instruments could be easily carried to great heights by means of ordinary kites. Hence the chief difficulty encountered was that of obtaining recording instruments adapted to use with kites. The tables of observations following this paper show that the average altitude of the first 22 flights at Blue Hill is almost as great as the average height reached in the 22 ascents of the Berlin captive balloon in 1890–92. (Meteorologische Zeitschrift, September, 1895, page 344.)

The following is a brief historical sketch of the work at Blue Hill. The first self-recording instrument (a thermograph), was raised on August 4, 1894; the first baro-thermograph, on August 19, 1895; the first Hargrave kite constructed at the Observatory was flown on August 18, and the baro-thermograph was elevated with this form of kite for the first time on September 21. The first thermo-anemograph was constructed in November, and this instrument (probably the first of the kind to be elevated by kites) was used regularly on and after November 16. Music wire was employed for kite line instead of cord on and after January 27, 1896. During this month, water-proof kites were employed during rain and snow storms. The height of one kilometer above the hill was reached for the first time on April 13. A baro-thermo-hygrograph of aluminium, constructed by Richard of Paris, was used for the first time on April 8, although similar heavier instruments had been carried in balloons. A height of 1.8 kilometers, or over one mile, was reached for the first time on July 20. At the suggestion of Mr. Douglas Archibald, a tail composed of

hollow cones was attached to one of the kites for the first time on July 23. A height of 2,000 meters was reached on August 1. The maximum height above Blue Hill, 2,665 meters, reached on October 8, is probably the greatest which a kite had attained at that time.

The primary object of the experiments was to obtain meteorological records at the highest possible elevations; and in attaining this result the forms of kites and accessory apparatus already known were employed at first, and such changes were made from time to time as seemed advisable from considerations of economy and increased efficiency. Much credit is due to Mr. William A. Eddy for his efforts to improve the kite, and to make it a useful instrument; and his personal assistance at the beginning of the experiments was of great value. Acknowledgments are also due to members of the Boston Aeronautical Society, to members of the Boston Scientific Society, and to Captain C. D. Sigsbee, U. S. N., for encouragement and assistance; also to Professor C. F. Marvin, who is in charge of the kite experiments of the Weather Bureau in Washington, D. C., and who has kindly allowed the Observatory staff to examine his apparatus.

The collection of meteorological data has occupied most of the time devoted to the experiments; therefore the improvements in the kites have not, perhaps, been so great in some respects as they might have been had the kite, as an instrument, been carefully and thoroughly studied before beginning the flights with the meteorograph. Some very useful and important advances have been made, however, and the plan followed has proved advantageous in indicating by practical experiment the kites best adapted to the work, and also in obtaining valuable meteorological records; thus securing the most economical use of kites and accessories. The experiments were conducted under the direction of Mr. Rotch; Mr. Clayton has had charge of the experiments with the Hargrave kites, and the reduction and discussion of the records; Mr. Sweetland has assisted in the flights, and in the reduction of the records; while the writer has had charge of the experiments with the Eddy kites, and has devised the mechanical appliances and instruments.

Methods of Constructing and Flying Kites.

Conditions under which Experiments were made. — Since the pressure of the wind alone is utilized in experiments with kites, the first step was to consider the means for employing this power to the best advantage. In order to obtain a clear understanding of the conditions to be met, it is well to give briefly the results of observations of wind velocity on Blue Hill. At this Observatory, the average recorded for the summer months is 7.5, for the winter months 9.3, and for the year 8.4 meters per

second. Near the ground the wind is extremely variable, the oscillations on either side of the mean velocity usually amounting to fifty per cent of the mean, and often exceeding this limit. The wind becomes steadier with increasing altitude, and the pressure becomes proportionally less on account of the decrease in density of the air with increase of altitude. But, since the pressure upon flat surfaces exposed normally to the wind increases in proportion to the square of the velocity, this relative decrease of pressure, due to rarefaction of the air, is not so rapid as the actual increase due to increase of velocity. From observations of clouds it has been ascertained that the velocity increases from 7 meters per second near the ground to 28 and 44 meters per second, respectively, for the summer and the winter half-year at an elevation of 9,000 meters; while, even at altitudes already reached by kites, it averages between 10 and 25 meters per second. Marked variations from these average conditions frequently occur, and it is safe to say that, for continuous use under average conditions at high altitudes, the kite must be light enough to be lifted by a wind of 5 or 6 meters per second, and strong enough to fly safely in winds of 15 to 25 meters per second; or, otherwise stated, strong enough to resist a pressure ten to fifteen times greater than that required to lift the kite. Obviously, the materials and workmanship must be of good quality to insure uniform results under such trying conditions, and in the experiments at Blue Hill they received first consideration.

Materials used in Framing Kites. — Of all materials used in constructing the frames of kites, spruce wood of fine quality proved the best, and, except for experimental purposes, it has been used in the construction of all the kites. Spruce wood is one of the lightest for its strength obtainable, and it is also quite elastic. Comparisons of the strength, etc. of different woods may be found in Lanza's Applied Mechanics and Thurston's Materials of Engineering. Some tests of white pine, and of poplar wood, and of steel umbrella-ribs were made at Blue Hill to ascertain their fitness for use in kite frames, but none of these materials equals spruce wood. The umbrella-ribs are heavier than spruce or white pine, and, without a complicated system of braces to stiffen them, are entirely too flexible. The expense and difficulty of working tubing made of steel and aluminium prevented experiments with these materials, although it is probable that light tubing might be used to advantage. In selecting spruce, it is necessary to obtain sticks entirely free from knots, and having a straight grain. A stick with the grain running diagonally is more easily broken than one containing a knot; but each is weaker than a straight-grained stick free from knots. The wood next best to spruce is white pine, which is more easily obtained than spruce. Bamboo rods were used in one kite, but it was almost impossible to secure a piece of uniform strength and rigidity.

Materials for Covering Kites. — For covering kites, several varieties of paper and cloth have been tried, and of these bond tracing-paper, nainsook, and silk are considered best. Common newspaper is too weak to be of use. Manila drawing-paper is excellent, though heavy; it may be obtained of various weights in wide sheets or rolls, — a great advantage in the construction of large kites. Bond tracing-paper is the strongest for its weight of all paper tried, and while its cost was about twice that of manila paper, it is only half as heavy, and is much tougher and more durable, — advantages that more than offset the greater cost. It may be had in rolls of fifty yards, the usual width being one yard (0.9 meter). Nearly all the kites used in the first year's experiments were covered with bond-paper, and under favorable conditions it gave excellent results.

The advantages of paper coverings are: (1) imperviousness to air; (2) smoothness; and (3) ease of preparation. Kites covered with paper, especially those of the Eddy pattern, appear to fly higher than those covered with cloth. The disadvantage of paper is its great lack of durability, — a very great disadvantage. When in use small punctures are made in the covering almost every time the kite touches the ground, and in time these so weaken it that it will not withstand an ordinary increase of wind pressure. Coverings of paper, especially those of large kites, will not endure long in a wind exceeding 12 meters per second; and in sudden gusts they have sometimes been blown into shreds before the wind became strong enough to affect the stability of the kite.

For cloth coverings, calico, common sheeting, cambric, percaline, nainsook, and silk have been tried. Calico is the cheapest of all these, and is light, but not strong or durable, and the widths are usually too narrow. Ordinary sheeting was the strongest material tested, but also the heaviest, and there is little to be gained by using it. Its chief advantage is the width: it can be obtained in pieces three yards wide. This simplifies the construction of large kites. Lonsdale cambric and percaline proved decidedly better than sheeting, because they are smoother, more closely woven, and much lighter than sheeting. The cost per yard is about the same as that of sheeting, but the width is usually one yard or less. Nainsook was found to be the best of the cotton cloths, although the most expensive. It is lighter than all others that were tested, and stronger than all others except sheeting. It can be had in widths of one meter or less. Silk is, no doubt, the lightest of all fabrics in proportion to its strength, but the samples tried were not very durable. Its other disadvantages are its narrowness, for it seldom exceeds thirty inches in width, and its cost, which is more than twice that of cotton. The lack of durability and the great cost make it doubtful if there

is much to be gained by using silk; nainsook is slightly heavier, but has the advantages of greater durability and smaller cost, which more than compensate for the greater weight.

The advantages of cloth covers are: (1) durability; (2) strength; and (3) the fact that they are not appreciably affected by moisture when used in rainy weather. Cloth covered kites apparently do not fly as high as paper covered kites, but this defect has been removed by filling the meshes of the cloth with several thin coats of varnish. Unfortunately, cloth so treated becomes brittle or rotten soon afterward, and in a few weeks is no better than paper. At the recommendation of Dr. J. E. Stanton of Boston, a varnish made by dissolving rubber in carbon disulphide was tried with good results, and one kite that has proved very durable was covered with the following mixture: —

Pure rubber	1 oz.
Spar varnish	4 oz.
Carbon disulphide . .	2 lb.

The rubber should be cut into very small pieces and dissolved in the carbon disulphide. This process requires several days. The varnish is then added, and the mixture is thinned with turpentine. Four very thin coats were applied to the kite, the first coat being allowed to dry before applying the others. Further experiments are necessary in order to determine the best varnish, because very few varnishes have been tried at Blue Hill.

Materials for Flying Kites. — Both cord and wire have been used successfully in constructing and in flying kites, and various specimens of different weights and strengths have been tested in order to select those of the greatest strength and durability. To obtain the average strength of any cord, a length of not less than 7 meters (23 feet) was tested by securing one end of the sample to some rigid support and the other to a strong spring balance, and then by pulling upon the balance until the cord broke. To measure great strains easily, one end of a rope was secured to the ring in the frame of the spring balance, while the other end was wound around the drum of the windlass. Specimens of most cords were broken several times in succession, in order to determine the average, as well as the extreme breaking strains. The results of the tests are shown in Tables XIII. and XIV.

The values given are approximately correct, but the cords vary considerably in weight, size, and strength. Weak places, less than half as strong as the average of certain samples, were found in some of those tested, and, to provide against loss, it was found necessary to test every piece of line used. One important

TABLE XIII.

Kind of Cord.	Diameter in Millimeters.	Weight per 100 Meters: Kilograms.	Average Breaking Strain in Kilograms.
Flax sole-thread, No. 8		0.10	36.3
" " " 9		0.17	37.5
Braided fishing line:			
Large, flax, soft-braided	3.0	0.75	63.5
Small, silk, " } " " hard-braided }	1.5	*0.05	20.4
Mattress twine, No. 13	1.5	0.28	22.7
Cable-laid cord, " 18	1.5	0.29	22.7
" " " 24	. .	0.30	27.2
" " " 48	2.0	0.42	35.4
Blocking cord, " 9	2.1	0.46	40.8
" " " 12	2.5	0.56	55.0
" " " 16	3.0	0.66	61.2
" " " 20	3.2	0.73	81.6
" " " 24	3.4	0.84	108.9
" " " 32	3.6	1.18	136.1

result of the tests was that some cords, proving very strong during the first test, rapidly became weaker when subjected repeatedly to a breaking strain. Certain cords selected for great strength, while in actual use as line for the kites, broke under strains much less than that adopted as a safe working strain; and, to ascertain if these cords actually became weaker, a few new samples were broken several times in succession. The results of some of these tests are as follows: —

TABLE XIV.

Kind of Cord.	Breaking Strain in Kilograms.		Loss in Kilograms.	Number of Tests.
	First Test.	Last Test.		
Sole-thread, No. 8	40.8	34.1	6.7	3
" " 9	45.4	27.2	18.2	3
Fishing line (large)	70.0	56.7	13.3	4
Blocking cord, No. 20	83.8	80.7	3.1	4

These tests show that the blocking cord was the most durable, the loss being but 3 kilograms out of over 80. The cords least durable were the shoe-threads and braided fishing lines. The shoe-threads are loosely twisted fibres of flax, and are

* Estimated.

very flexible. As the table shows, these cords were the lightest of all, considering their strength, but were not sufficiently durable for use as lines for flying kites. The braided fishing lines were samples sent to Blue Hill by a manufacturer, to be tested. They consisted of a few straight fibres of silk, or of linen, over which was braided a cover of the same material. Hard and soft braids were tested, but there appeared to be very little difference in strength between the two kinds. The samples were quite strong, but the durability of these was little greater than that of the sole-thread. The mattress twine was a twisted flax line and was strong considering its weight, but no large sizes were procurable. It was not so durable as the blocking cords. The cable-laid twines and the blocking cords (which resemble cable-laid twine) were the best and most durable of all the cords tested. These are hard-twisted linen lines and are obtained of several sizes and strengths. They are heavier than the shoe-threads and the braided lines, but their great durability renders them superior to loose-twisted and braided lines. Blocking cord was used for a main line during 1894 and 1895, a line 1,100 meters in length being employed until January, 1896; and it has since been used as secondary lines for kites flown tandem. The length of single pieces of cord was usually less than 100 meters, and in uniting several short lengths to form the main line great care was taken to secure strong knots and splices. The knot used by Mr. Eddy is called by him the surgeon's or the fisherman's knot, and, being easy to tie and very durable, it was used in making up the main line. This knot is shown in Plate II. Figure 12. The bowline knot was also used in some parts of the line. This can be recommended as a good knot, although it is less compact than the surgeon's knot. For attaching lines to the kites, an ordinary running noose is generally used, the knot being tied with a loop so that it can be readily loosened. For attaching secondary lines to the main line, the device shown in Plate II. Figures 9 and 10 was used at the suggestion of Mr. J. B. Millet. Two half-hitches are formed in the main line, and these are tightened around an eyelet into which the secondary line is tied or secured by means of a toggle, as in Plate II. Figure 4. The eyelet is easily removed when the strain is taken off, and is a perfectly safe device for attaching secondary lines, or instruments, to the main line.

Cord proved to be excellent for ascensions to small heights, but, on account of its great weight and large surface exposed to the wind, it was almost impossible to reach altitudes of 600 meters while using it as a main line. The area of the line of 1,100 meters was nearly 3 square meters, and, although this surface was never normal to the wind, the effect of the pressure of the wind was so great that the angular elevations were generally low.

Steel music wire, commonly known as "piano wire," having been used in deep-sea sounding, and by Archibald in his experiments with kites, this material was tried for a main line. Upon request, early in December, 1895, Captain C. D. Sigsbee, U. S. Hydrographer, kindly furnished the Observatory with information concerning the use and care of wire, but it was not until January 27, 1896, that the sample of wire first obtained was used as a main line. This sample proved very satisfactory from the beginning, and more wire was purchased from time to time, until, by September 15, the main line employed was 5,500 meters in length. Two sizes of wire have been used, and the chief elements of these are given below: —

Music Wire Gauge: Number.	Diameter: Millimeters.	Weight per 100 Meters: Kilograms.	Breaking Strain: Kilograms.
12	0.71	0.34	90 to 96
14	0.81	0.42	131 " 140

Referring to Table XIII., and comparing the above measurements of wire with those of the strongest cords, it will be seen that the wire is less than half as heavy and less than one fourth the size of cord of the same strength. Figures 7 and 8 (Plate II.) show approximately the size of music wire and blocking cord of the same strength. Also, the wire is polished smooth, which reduces the friction caused by wind blowing past it. Music wire, being highly tempered, is easily injured by the formation of small sharp bends or kinks, and care must be taken to keep it taut when unwound from the reel or the coil. Single pieces 2,500 meters in length may be obtained from the manufacturers; hence but few splices are necessary in a line of considerable length. The methods of splicing this wire are different from those used in uniting telegraph wires, since for the sake of durability and safety, no close twists or bends should be allowed in music wire. The splice used at Blue Hill is similar to one recommended by Commander Sigsbee, and is made as follows. The ends of the wires to be united are thoroughly cleaned and laid together, not twisted, for a number of turns, as shown in Plate II. Figure 6; then a seizing of very small annealed wire is put on near each end. The extreme ends of the wire are wrapped close around the standing parts at the end of the splice, and the whole is covered with soft solder by means of a soldering iron or, still better, by drawing the splice through a groove in a piece of board in which a small quantity of solder is kept fluid by means of a soldering iron. By the use of this method all danger of weakening the wire by overheating it is avoided. The length of the original Sigsbee splice was about 18 centimeters, but it was found necessary to increase the length to 30 or 35 centimeters in order to insure durability. To acquire the knack of laying the wires together uniformly takes some practice in order to make a strong, durable

splice; but the knack is easily acquired, and the only tools necessary are a soldering iron and plyers to hold one end of the splice while the wires are being laid against one another. Projecting ends of the wires may be removed by means of cutting plyers. The splice may be smoothed by a file or by sand-paper, but this is not absolutely necessary; and since all abrasions of the single strands of wire reduce their strength, filing should be done carefully, and only upon the parts of the splice covered by solder. The method of attaching kite lines, etc. to the end of the wire is shown in Plate II. Figures 4 and 5. The end of the wire is coiled twice around an eyelet, and the free end is spliced with the standing part in the same manner as that shown in Plate II. Figure 6. Since this connection receives more usage than other splices, it is important to exercise, if possible, greater care in preparing it. The loops around the eyelet must be so tight that the eyelet cannot be forced from them by unequal strains, and the end of the splice must be made smooth to avoid loosening the wrapping, should the wire be dragged over any obstacle.

For attaching secondary lines at any point on the main wire, the clamp shown in Plate II. Figure 11 has proved very satisfactory. The clamp consists of an angular casting of hard aluminium, the ends of which are slotted to receive the wire. The slot is cut by a saw slightly thinner than the diameter of the wire, and is opened by a wedge until the wire will pass just behind the clamp screws. Ordinary thumb-screws for use by hand, or machine screws for use with a screw-driver, may be used to tighten the clamp. The clamp is secured to the wire with the short arm toward the outer end of the wire, so that the pull of the secondary line will be nearly equal upon both arms. The secondary line is attached by the running noose, bow-line knot, or, still better, by the toggle shown in Plate II. Figure 4. No injury to the wire has occurred since this clamp was used, and its only defect is that considerable time is required for its attachment and detachment. Attempts have been made to devise a clamp that could be attached and detached instantly, but so far without success. Eyelets can be secured to the wire in the same manner as to cord, but, on account of the difficulty of handling the wire while it is under strain, they were not often employed. Eyelets fastened permanently to the wire are objectionable, because when they are used kites can be attached only at fixed points, and moreover the winding of the wire over eyelets or other obstructions produces noticeable bends that may in time weaken the line. Slight bends are apt to crack or to split when they are straightened and bent many times, as occurs when the wire is used repeatedly; they are always a source of danger. It is the practice at Blue Hill to keep the line entirely free from such defects.

Windlass.—During the first season's experiments, the windlass consisted of a large spool, such as is used in storing insulated wire, mounted in a suitable box, which was secured to a wheelbarrow, for convenience in moving it about. A device for measuring the length of the line was attached in August, 1895. This rather crude windlass served its purpose very well, but was not very strong; and in September, 1895, it was replaced by the heavier apparatus, shown in Plate II. Figures 13, 14, and 15. This was built after the pattern of the ordinary portable hoisting windlass. The frame is of hard wood, and is mounted upon wheels. The drum, *A*, containing the cord or wire, is 15 centimeters in diameter and 30 centimeters in length, and is provided with heads 35 centimeters in diameter, which are strengthened on the outside by iron flanges 15 centimeters in diameter and 2 centimeters thick. The drum is clamped to a steel shaft 2.5 centimeters in diameter, and provided at each end with a crank, *G*, *G*. To regulate the speed of the drum when line is reeled out, a hand-brake, *F*, is arranged to bear against one of the drum-heads. The device for measuring the line is secured to the frame in front of the drum. It consists of a hard-wood grooved pulley, *B*, exactly 50 centimeters in circumference, and is provided with registering dials (shown at *C*) for indicating the number of revolutions. The pulley and dials are mounted in a frame which also carries an oil reservoir, *D*. This register moves freely backward and forward upon the guides *H* and *J*, and thus adapts itself automatically to all changes in position of the wire. The stops, *I*, *I*, serve to limit the movements of the register, and they can be clamped in any desired position. The position taken by the wire is shown by the line *E*. It passes under the pulley without going entirely around it. This register was carefully tested by winding known lengths of line through it; and the tests show that it is extremely accurate, the errors rarely amounting to one half of one per cent. The uniformity of its action is shown by the fact that the dials have not registered an excess or deficiency amounting to 20 meters since the beginning of the experiments. The largest differences were observed when over 5,000 meters of line had been let out and reeled in, making 10,000 meters in all, with a difference of but one fifth of one per cent. There is very little, if any, slipping of the line when it passes under the pulley at speeds varying from 1 meter to 5 meters per second. The length of line let out is read directly from the dials, without the necessity of applying a correction for the varying amount of wire on the drum, as is necessary when a register is connected with the axis of the drum.

To prevent the wire from rusting it is necessary to keep it covered with oil. A satisfactory method of applying the oil is to allow a small quantity to drop from

the reservoir, *D*, upon the measuring pulley as the wire passes under it. The flow of oil is regulated by a stopcock; and usually about 25 drops per minute prove sufficient. In extremely cold weather, when oil solidifies, the wire is passed over cloths saturated with oil or grease.

The simple drum of hard wood, already described, proved strong enough for storing cord under considerable strains; but after wire was adopted for a main line, the drum-heads were spread apart when a thickness of scarcely 2 centimeters of wire had been wound on the drum at a moderate strain. The drum next made was of hard wood, the core being 18 centimeters in diameter and 15 centimeters in length; it was provided with heads 27 centimeters in diameter and 3 centimeters thick. Outside the heads are placed flanges of the same diameter as the heads, and 2 centimeters thick. The heads are prevented from spreading by three iron bolts passing lengthwise through the core of the drum. This drum was in use during 1896 until October, when it was replaced by the one illustrated in Plate II. Figure 15. This is essentially the same as the preceding, except that it is twice as long, and the heads contain a recess into which the core fitted. This recess was made to provide for spreading apart of the drum-heads in case the crushing effect of the wire became excessive. In the figure, *A* is the core, of hard maple, the ends of which fit smoothly, to a depth of 1 centimeter, into the heads *K*, *K*, which are 4 and 6 centimeters thick respectively. The flanges, *L*, *L*, and the heads, are securely held to the core by the bolts, *M*, *M*, which are placed beneath the surface of the core. The drum complete, with two cranks 20 centimeters long, weighs 40 kilograms. One of the heads is very thick, to provide a good bearing surface for the brake. This drum proved strong enough for the work, but the crushing effect of the wire will probably destroy the wood which is immediately exposed to it; and it seems that the only drum suitable for continuous use should be made of heavy cast iron or of steel. The pressure of the wire appears to be proportional to the number of turns wound upon the drum, and, according to a calculation by Commander Sigsbee, this pressure sometimes amounts to several tons for each layer of wire. The drum used by Sigsbee was about 0.5 meter in diameter, and was built of steel. On a drum of this large size, the pressure of the wire is not so concentrated as it is upon one of smaller diameter.

One method of avoiding the excessive and cumulative strain of the wire, employed in deep sea sounding apparatus, is to use the strain-pulley. Several turns of the wire are passed around a grooved pulley, the wire on one side leading on, and on the other passing off to a storage drum turned by a loose belt which moves it with force only sufficient to receive the wire under a very slight tension. Such a device would make the portable windlass much more complicated, and perhaps too

heavy to be easily moved; therefore it was not adopted. Full descriptions of this, and of other devices for handling wire, are given in Commander Sigsbee's book, Deep Sea Sounding and Dredging (U. S. Coast and Geodetic Survey, 1880). One of these devices is that used for transferring a loose coil of wire to the drum of the windlass. Music wire is usually sold in coils, and to wind it upon the drum of the windlass it is necessary to mount each coil upon a spool so that the winding may be smooth and kinks may be prevented. This special device has not been used at Blue Hill, because, upon request, the manufacturers wound the wire upon spools, and its transfer to the windlass was easily and safely effected.

Cranks of 20 and 30 centimeters in length were tried, and the labor of winding was less when the shorter cranks were used; therefore these cranks were adopted for general use. The complete windlass, with 5,500 meters of wire on the drum, weighed about 150 kilograms, but it could be moved easily by one man, and placed in any favorable situation. In this respect, it was superior to a stationary windlass, because there is no place on the summit of the hill where the exposure is uniformly good, except on the Observatory tower, and there the line would interfere with the instruments.

Dynamometer. — The pull upon the line was measured by attaching an ordinary spring balance to the drum. Frequent readings of the balance gave valuable data concerning variations in the pull. It was decided to make this device self-recording, but though the mechanism has been designed, as yet it has not been constructed.

In addition to the knowledge concerning the pull of the kites gained by using the dynamograph, an approximate measure of the wind velocity may be obtained if but one kite is attached to the wire, provided due allowance is made for the weight of the wire and the kite, the density of the air, and the angle of incidence of the kite to the wind. However, such results at best are inferior to direct measurements of wind velocity, and they require much more work; and as at least two kites were always attached to the line, the method is not used at Blue Hill.

Instruments for Measuring Angles. — During the first experiments, the angular altitudes of the kites were obtained by means of the rough altitude instrument shown in Plate II. Figure 16. Upon a board, *A*, one edge of which is provided with sights at the corners, *C* and *D*, is graduated an arc of a circle, the centre of which is the corner *C*. From this corner is suspended by a light thread the weight *B*. When the edge *C D* of the board is in a horizontal position, the cord intersects the graduated arc at its zero, *O*. On raising the end of the board, as shown in the figure, the cord passes over successive divisions of the arc, and indicates the inclination of

the edge $C\ D$ with the horizon. To make an observation, the sights C, D, are set to coincide with the line of sight from the eye to the kite, or to the meteorograph, and the string indicates the altitude. During 1895 was used a Casella pocket alt-azimuth, which differs in principle from the instrument just described in that the altitude is measured by a pivoted graduated disk which is loaded on one side. The disk always hangs with the loaded side down, and when the sighting tube, to which is secured the index, is inclined from the horizontal, the index shows the amount of inclination. This instrument is more accurate than the one first described, and the readings are probably correct within one degree of arc. In the spring of 1896, a rough transit was made, the circles of which are 13 centimeters in diameter, and are graduated to half-degrees. The telescope magnifies about ten diameters, and the readings are usually correct within 0°.3, which is sufficient for the purpose.

Kites.

The following kites have been tried at Blue Hill : —

1. Archibald's flat diamond-shaped kite, with tail composed of hollow cones.
2. Cabot's rudder kite.
3. Eddy's tailless kite.
4. Eddy's kite, with cross-stick in the form of a dihedral angle.
5. Clayton's keel kite.
6. Hargrave's cellular kite.
7. Clayton's modified Hargrave kite.

A number of modifications of the above kites also were tried.

1. The coverings of the tailed kites were from the original kites employed by Mr. Archibald in his experiments in 1883. They were purchased of Mr. Archibald by Mr. J. B. Millet, who kindly sent them to the Observatory for trial. The original frames were of a fine quality of bamboo, but, this material being difficult to obtain in Boston, the new frames were of spruce. Two sticks were used, the central stick being 1.5 and the cross-stick 1.0 meters in length. The sticks were lashed together at a point about one third of the length of the central stick from its upper end, and their ends were fitted into pockets at the corners of the covering, which was made of Tussore silk. The tail consisted of a cord five or six times longer than the kite, carrying at its lower end two or more light cones made of cloth. The cones are attached as shown in Plate III. Figure 21, with the open ends toward the wind. A ring in the open end prevents collapsing of the cone. This kite, although seemingly very stable through a wide range of wind velocity, did not attain a high angular altitude, and it was never used in the flights with instruments.

2. This kite was designed by Mr. Samuel Cabot of Boston, who has constructed some very large kites of this pattern. The kite is of the well known hexagonal shape, and at the rear end is secured a disk-like rudder (see Plate III. Figure 22). A is the kite, which is here represented as a single flat surface, and B is the rudder. formed of a hoop of very flexible bamboo covered with cloth and firmly lashed to the frame of the kite. The specimen tested at Blue Hill was about one meter long and a half-meter wide. It flew quite steady in winds averaging 3 to 8 meters per second, and reached a high angular altitude, but it was unstable in winds stronger than 8 meters per second. One remarkable feature of this kite was its stability after the string was released. On one occasion, when the kite was attached to about 60 meters of light cord, it broke away, and before falling to the ground it was carried 1.6 kilometers, a horizontal distance of twenty times its vertical height above the earth.

3. The details of Eddy's kite are shown in Plate III. Figures 17 to 20. This kite consists essentially of two sticks, AB and CD, of nearly equal length, crossed at right angles. They are lashed together at a point distant from the top by 18 per cent of the length of the central stick, CD; the cross-stick, AB, is bent backward in a bow (the depth of which is about 10 per cent of the length of the stick) by means of a cord attached in the usual manner of a bow-string. The ends of the sticks are notched to receive the cord which forms the edge of the kite. This cord is firmly secured to all the corners except the one at the top, where it is usually tied with an adjustable bow-knot. It is important that the sides of the kite, AD and BD, should be equal, so that the surface of the covering may be equally divided between the two sides of the central stick, CD. This kite is easily constructed and is a distinct advance beyond other single surface kites. The angular height attained was greater than that of the other kites; and the best made Eddy kites flew with steadiness through a wide range of wind velocity. It seemed desirable to improve this kite still more; and while the same proportions are retained in the later forms of this kite, the construction is now very different.

4. The weakest part of the original kite was the bowed cross-stick, AB (Plate III. Figure 17). While bent, this stick is constantly under strain, which increases when the kite is flown, because the pressure of the wind forces the stick backward in the direction in which it is bent. In some of these kites, especially those of larger sizes, the cross-stick is bent backward by the pressure of the wind alone. This strain is liable, if the stick is not of uniform strength, to bend it unevenly, causing the kite to sag badly toward the bent side; or if the stick is of uniform strength, it is easily broken in strong winds. The form of cross-stick shown in Plate III. Figures 19

and 20 was adopted as a substitute for the bow. It has proved very satisfactory, not one in ten having broken. This device is nearly the same as that used by Sir George Nares in 1861, in the storm-kite designed by him, and which is described in the Scientific American Supplement for September 10, 1892. In the figures, *B* is a short piece of square tubing, one side of which is slotted to receive the central stick, *A*. The ends of the two pieces forming the cross-stick, *D, D*, are driven into the open ends of the tubing, which is bent at the slot to the desired angle, as in Plate III. Figure 19. When this is done, the jaws of the slot clamp the central stick firmly, and usually no lashing with cord is necessary. A piece of wood, *E*, is secured firmly to the cross-sticks, which may be further strengthened by the brace, *F*. An advantage of this form of construction is, that, if one stick becomes damaged, it may be replaced by a new one without disturbing the others. All the joints are first coated with glue, and then with varnish or with paint. Greater rigidity of the frame is obtained by sticks made in the form of a T-rail, as in Plate III. Figure 20. Two flat sticks, say of 1×2 centimeters in cross-section, are secured together by glue and brads, with the edge of one against the flat side of the other. Varnish or paint will prevent this joint from working loose in damp weather.

Following a plan suggested by Dr. Stanton, the cover of the kite was made separate from the frame, and then tied to it. In order to do this in the best manner a diagram of the actual size of the kite (see Plate III. Figure 17) was drawn upon the floor of the workshop, and screws were placed at the corners *A, B, C*, and *D*, with their heads projecting about one centimeter above the surface of the floor. The cloth cover was then tacked to the floor outside the edges of the diagram, and the screws were forced up through it. The cord for the edges of the kite was then placed outside the screws, and was tied at the upper corner, *C*, a knot also being made just below each of the corner screws at *A* and *B*, in order to prevent the ends of the cross-stick from slipping when the cover is tied to the frame. The cover was pasted over the cord, the paste being rubbed in thoroughly, and a uniform smooth seam was made except at the corners, where the cord was left bare for about five centimeters. The completed cover was not removed from the screws until it was thoroughly dry. The bare portions of the cord at the corners were firmly lashed to the ends of the sticks, care being taken to bring the knots at *A* and *B* firmly against the lower edges of the cross-stick. The ends of the cross-stick are liable to slip downward when the cover is tightened, and the knots check this tendency very satisfactorily. The cover was firmly lashed to the sticks at the corners except at the top, *C*. At this point, the ends of the cord, which are left bare for a distance of several centimeters, are united

by means of a square bow-knot, and are placed in the groove in the top of the stick. This provides for adjustment of the tension of the cover, which, as the kite is used, requires occasional tightening.

The bridle or hanger is attached as shown in Figure 18. The upper part of the bridle, *G*, forms nearly a right angle with the surface of the kite at *E*, and in length from *E* to *I* is usually equal to one half of the width of the kite from *A* to *B*. The ring *I*, to which was attached the flying string, is secured to the bridle by a half-hitch, its exact position being determined by experiment for each kite; but it is usually placed between the two cross-marks shown in the figure.

TABLE XV.

ELEMENTS OF THE EDDY KITES.

Designation of Kite.	Length of		Size of Sticks: Millimeters.	Approximate Area of Cover: Sq. meters.	Total Weight of Kite: Kilograms.	Weight per Sq. Meter: Kilograms.
	Central Stick: Meters.	Cross-Stick: Meters.				
5-foot	1.52	1.52	6.3 × 12.7	1.07	0.4	0.37
6 "	1.83	1.83	9.4 × 19.0	1.53	0.7	0.44
7 "	2.13	2.13	12.7 × 22.1	2.00	1.1	0.55
9 "	2.74	2.74	12.7 × 25.4	3.30	1.8	0.55

These dimensions were originally expressed in English measures, the designation of the kite being the length of the central stick in feet; this explains the occurrence of odd fractions of a meter in the columns containing the dimensions.

The kites described above flew in winds averaging between 5 and 18 meters per second at the ground, and at angular altitudes of 55 to 65 degrees. At a velocity of 10 meters per second, the average pull on the line was 5 kilograms per square meter of total surface. The improvement in this form of kite has been chiefly in the pull, the angle having increased but little. The pull of the kites constructed at the beginning of the experiments averaged scarcely 2 kilograms per square meter in a wind of 10 meters per second, or less than half that exerted by the improved kites.

Kites that become distorted and fly at a tangent to the mean direction of the wind can usually be corrected by tying a short piece of string diagonally across the side toward which the kite flies. The position of such a cord is shown by the dotted line, *F*, in Plate III. Figure 17. The effect of the string is to change the form of the cloth surface, flattening it so that the wind has greater influence upon it, and thereby restoring the balance so that the kite will fly well throughout its usual range of

wind velocity. A common method of correcting a distorted kite is to tie a weight on the side opposite to that toward which it leans; but since this does not in the least alter the form of the surface, the balance of the kite is restored only when the wind velocity is between certain narrow limits; when it is higher or lower than these limits the kite sags to one side or the other, according as the effect of the weight is neutralized by the unequal pressure of the wind.

An attempt has been made to adapt the Eddy kite to a greater range of wind velocity by making the surface so rigid that the shape of the kite would be retained even under great pressure. The edges of one kite have been made of wood and braced by struts so that they would not bend backward when flown in a strong wind. The dimensions of this experimental kite are the same as those of the 7-foot kite in Table XV. The cover is left somewhat loose that it may form over the central stick a side-plane a little wider than is usually allowed in the Eddy kite. This kite did not fly with any arrangement of the bridle in any wind, but after the rigid edges and the braces were removed it flew as well as any of the Eddy kites. This experiment proves that the backward bending of the edges below the cross-stick is one of the chief causes of stability in the Eddy kite, and one which cannot be dispensed with, and that, in order to obtain still greater stability, experiment must be made in other directions.

By the addition to the Eddy kite of the special tail already described, greater longitudinal stability is obtained. The strings bearing the cones are usually two to three times as long as the kites, and when but one cone is employed the diameters and the lengths of the cones for kites of various sizes are as follows: 5-foot kite, 20×30 centimeters; 6-foot kite, 25×35 centimeters; 7-foot kite, 30×40 centimeters; 9 foot, 40×50 centimeters. These dimensions are only approximate, because considerable variations may be made without much effect on their flight. The cones are very useful; and in some cases, when the kites will not fly at all, the addition of the cone restores stability. One great disadvantage of tails of any kind is their liability to entanglement with the lines of other kites when flown tandem, which is sometimes the cause of great annoyance. For this reason, the kites having tails are almost always placed at the end of the main line.

5. The keel kite was designed by Mr. Clayton in December, 1896. It consists of a single surface, either flat, curved, or composed of two planes at an angle to each other. The sticks preferably cross at a point about 20 per cent of the length of the central stick from its top end. In front of the kite, and forming a part of the central stick, is a vertical plane, the width of which is usually about one third that of the kite. Its form and the manner of attaching the bridle are shown in

Plate III. Figure 23. The lower part, *A*, of the bridle is elastic, and when the wind is strong this elastic part stretches and allows the angle of incidence of the kite to the wind to become less, thus slightly decreasing the pull without decreasing the stability. Designed originally for use in extreme ranges of wind velocity, this kite has proved quite successful, flying well in winds of 5 to 25 meters per second, at an angular height equal to that reached by the other kites under more favorable conditions. The chief defect of this kite is its liability to distortion, and also the difficulty of restoring it to a normal condition after its symmetry has been disturbed. The results obtained with the keel kite, however, are far from discouraging, and experiments are being made with a view of removing these defects.

6. The first Hargrave kite built at Blue Hill in August, 1895, had the same dimensions and weight as the smallest of those described by Mr. Lawrence Hargrave in Engineering for February 15, 1895. It is shown in Plate I. Figure 1. The dimensions of the kites of this pattern given in Table XVI. are thus measured in Figure 1. *A B* is the width, and *B C* the length of the kite; *A E* is the depth, and *E G* the width of the cell. The cells consist of single bands of cloth stretched over rectangular frames of spruce wood; these are mounted on a central truss or spine, the sticks of which are heavier and stronger than those forming the corners of the cells. The edges of the cells are stiffened by a cord in the hem of the cloth, but are not unyielding. This kite flew with remarkable steadiness, but at a rather low angle compared with that attained by the Eddy kites. The principal causes of this were the flapping of the cover, which became loose while the kite was flying, and the lack of rigidity of the frame. Mr. Clayton, who made nearly all the experiments with the Hargrave kite, has greatly improved this kite by making it lighter and more rigid than the original. The details of the improved kite are radically different from those of the original, and, to distinguish it from the others, it is called the modified Hargrave kite. Two experimental forms are shown in Plate I. Figure 1 shows the original Hargrave kite. It was necessary to alter the construction of this kite, for the following reasons. 1. The pressure of the wind upon the diagonal braces in the cells caused the kite to fly at a comparatively low altitude. 2. The cells were not rigid and were easily distorted. 3. The absence of connection between the outer ends of the cells allowed the kite, when flown tandem, to catch on the main line. When thus caught, it could not be dislodged until drawn to the ground.

Plate I. Figure 2 shows one of the earliest attempts to improve this kite, and this is the simplest of all that have been tried. The frame is composed of but

eight sticks, — four extending longitudinally through the corners, and connecting the two cells; and four extending diagonally across the cells, and secured at their ends to the longitudinal sticks. The defect of this kite is its liability to become distorted. The diagonal sticks easily bent under pressure on account of their extreme length. The extension of the longitudinal sticks through the entire length of the kite prevents the corners from catching on the main line when the kite is flown tandem; therefore this device has been retained in subsequent forms.

A more complicated, but more efficient form, is shown in Figure 3. In this form the longitudinal sticks are supported by sticks extending laterally across the upper and the lower planes of each cell, and by short uprights at the side of each cell. A modification of this kite contains but one lateral stick extending through the middle of each cell, and supporting the longitudinal sticks by the short uprights. The objection to this form is, that all the strain comes upon the two cross-sticks, as in the kite shown in Figure 2. In another kite the cells were connected at the lower corners only, but this resulted in loss of rigidity, and no others of this pattern have been made.

7. The Hargrave kite as modified by Mr. Clayton is shown in detail in Plate III. Figures 24, 25, 26, 27, and 28. The chief deviation from the original Hargrave kite is the elimination of the central truss or spine, and the extension of the sticks at the corners of the cells through the entire length of the kite, thus rigidly connecting the two cells and rendering it impossible for their relation to each other to become disturbed. This method of construction greatly simplifies the kite, because in the new kite four long sticks are made to serve the purpose of the ten in the old kite. This method has been used in all the kites made since August, 1895. In the first kites of this improved form, made in September, 1895, the diagonal pieces (*D*, *D*, in the old kite shown in Plate I. Figure 1) are replaced by a single straight bar extending across each cell and supporting the four corner sticks by an upright at each end. The cover is laced on, and its tension is adjustable. The sticks at the corners of the kite are united by the device shown in Plate III. Figure 27. Two thin strips of aluminium of the same width as the sticks are bent to an angle, and secured to the sticks *A* and *B*, which respectively form the horizontal and the upright sticks of the cell. The longitudinal stick, *C*, passes through the square opening or slot formed by the ends of the other sticks and the outer aluminium strip. The angular pieces are secured to the sticks *A* and *B*, by cord or by small bolts, as shown in the drawing, and the stick *C* is fitted smoothly into the slot. The kite can be easily taken apart by sliding the stick *C* out of the slot. This new kite is much lighter and more rigid than the one first constructed, and several

have been made for use. The angular altitude reached was lower than that attained by the Eddy kite, and further improvement became necessary. The fluttering of the cloth cover in the wind was probably the cause of this defect, and in the next kite constructed the edges of the cloth were stiffened by thin sticks of lenticular cross-section, which present but little surface to the wind. This method of construction is described by Mr. Hargrave in the Proceedings of the Chicago Conference on Aerial Navigation, in 1893, and it was used by Mr. C. H. Lamson in a large kite built during the summer of 1895. (See articles by Hargrave and Lamson in Means's Aeronautical Annual for 1896.) Professor Marvin has also pointed out the advantages of stiffening the edges of the cells in the Monthly Weather Review for May, 1896. The details of one of the cells of the new kite are shown in Plate III. Figure 26. The angular connection shown in Figure 27 is used to connect the sticks at the corners, *A*, *B*, *C*, *D*, (Figures 24 and 25,) and, in order to render the frame rigid, wire guys, *F*, *F*, are stretched diagonally across the cell, connecting the corners. These wires are placed on every side of the cell, those on the vertical sides extending the entire length of the kite. The dotted lines show the positions of the sticks and wire guys covered by the cloth. The cloth is secured to the sticks by paste or by sewing the cloth around them. The structure previously described is much more complicated than the original Hargrave kite, and slightly heavier; also the time required to construct it is much longer than that required for any of the other kites. The advantages of the several modifications are great, because the new kite will fly at a very high angle, which is nearly, if not quite, equal to that attained by the Eddy kites; while the pull and the stability are not impaired. These improvements led to the more general adoption of the new form of Hargrave kite. Since the dimensions of the kites may be varied considerably without appreciably altering the stability, it is probable that a still more efficient form may yet be devised. Experiments on wind pressures have shown that the pressure upon an inclined surface, such as a kite, is always greatest on the front end; and with the object of arranging the rear cell so that it should not be sheltered by the front cell, a kite was built with the two cells separated by a space of more than twice the width of their cells. Since no appreciable advantage resulted from this, the rear cell of the next kite was made about one tenth wider than the front cell, the two cells being separated by a space a little wider than the rear cell. As a result, the kite attained the highest angle reached by any of the Hargrave kites; and, since this is the chief result desired in kites for reaching great elevations, all the Hargrave kites are built at present according to this plan. The dimensions of the Hargrave kites employed in the flights are given in the following table.

TABLE XVI.

ELEMENTS OF THE HARGRAVE KITES.

Width of Kite: Meters.	Length of Kite: Meters.	Depth of Cell: Meters.	Width of Cell: Meters.	Lifting Surface: Sq. Meters.	Cross Section of Sticks: Sq. Millimeters. Lateral.	Cross Section of Sticks: Sq. Millimeters. Longitudinal.	Total Weight of Kite: Kilograms.	Weight per Sq. Meter of Lifting Surface: Kilograms.	References to Drawings.
1.52	1.80	0.57	0.58	3.58	240	320	2.47	0.69	Plate I. Fig. 1.
1.12	1.32	0.46	0.41	1.84	200	200	1.56	0.85	Plate I. Fig. 3.
0.91	1.22	0.41	0.41	1.49	40	80	0.82	0.55	Plate III.
1.22	1.82	0.46	0.46	2.13	110	110	1.64	0.77	Figs. 24 to 28.

The lifting surface is assumed to be the total surface minus the side planes. The sticks have a rectangular or an elliptical cross section.

Several kites of each of the sizes given above have been made, each frame being slightly different from the others. All these kites are very stable, and fly in recorded wind velocities of from 6 to 20 meters per second. The angular altitudes reached by the first two kites average between 45 and 55 degrees, and those reached by the last two average between 50 and 60 degrees. The pull in a recorded wind of 10 meters per second averages about 5 kilograms per square meter of lifting surface. The bridle used is shown in the Plates.

Method of Testing Kites. — Since the use of kites for elevating instruments is to reach considerable heights, the kite which attains the highest angular altitude — other things being equal — is best adapted to such use. Another requisite of nearly equal importance is stability, without which the use of the kite is limited only to the most favorable conditions. To these may be added two other factors, — simplicity and durability. All these considerations are sought for in the kites employed at Blue Hill.

The method of testing kites is to fly them with a short line, usually 50 to 100 meters long, and to make frequent and regular observations of the angular altitude and of the pull. The instruments employed are an alt-azimuth or a surveyor's transit, and a spring balance. Tests are usually made under widely varying conditions of wind velocity, in order to determine the fitness of the kites for use in all velocities. By these tests, the kites flying at the highest angles and through the greatest ranges of wind velocity, and those exerting the greatest pull, are easily selected; or, in other words, this method of testing shows the relative capacity of the kites for performing work, which, in this investigation consists of raising a meteorograph of known weight under varying conditions.

The estimate of the usefulness of the kite should also include some consideration of its durability, and of the time necessary to keep it in good condition. The materials used in constructing kites are more or less fragile, and are easily affected by atmospheric changes, especially when they are under strain. Therefore simplicity of construction should be given first consideration. At Blue Hill the simpler forms are preferred, and no complex structures are employed unless there is a decided advantage to be gained by their use.

Analyses of the forces acting upon kites are given by Mr. A. Samuelson in the Zeitschrift für Luftschiffahrt for December, 1895, and by Professor Marvin in his pamphlet, Kite Experiments at the Weather Bureau, published in 1896 by the United States Weather Bureau, Washington, D. C.

Flights with the Meteorograph. — In flights with the meteorograph the kites described in paragraphs 3, 4, 6, and 7 were employed. Plate VIII. shows the appearance of two of these kites while flying. In any flight kites are selected with reference to the prevailing conditions of wind and weather. Usually, two kites of size sufficient to lift the meteorograph to a good angular altitude were used, allowance being made for possible increase of wind velocity with increase of altitude, so that the strain upon the line shall not much exceed one third of its tensile strength. The meteorograph is suspended from a ring at the junction of the two kite lines with the main line, as shown in Plate IV. Figure 32. Other kites are attached when permitted by the decreased pull due to the weight of added line. In Table XIX. are given the details of the flight of August 26, 1896, which show the observations usually made at the ground during a flight.

Meteorographs.

The recording instruments employed in this investigation are of the Richard pattern, lightened and modified to suit the exposure which is essentially different from that of instruments mounted upon a fixed support, or lifted by a free balloon. The constant oscillations impressed upon the instrument by the motions of the kites supporting it, or by the varying pressure of the wind upon the instrument itself, may cause larger errors than are found in the record of the stationary instruments. Such errors are due to flexure of parts of the recording mechanism, or of its supports. Errors due to sluggishness of the instrument or to friction are apparently smaller in the kite meteorographs than in the fixed instruments, because the oscillations of the former prevent the pivots or arbors from sticking. Errors are prevented as far as possible by mounting the recording mechanisms on rigid supports, by careful adjustment of the various parts, and by frequently cleaning the bearings, etc.

Errors due to exposure of the instrument are not so easily corrected. The exposures of the barograph and of the hygrograph are not of great importance, because errors due to temperature or to the wind are much smaller than those due to other causes. It is sufficient to expose the sensitive parts so that a free circulation of air around them is secured. The suitable exposures of the thermograph and the anemograph are the greatest difficulties encountered.

The results of the investigations of thermometer exposure by many authorities, and especially by Dr. R. Assmann, may be summarized as follows: —

1. The bulb of the thermometer should not be connected directly with any part of the instrument exposed to direct sunlight. 2. It should be screened from direct sunlight by means of double walls, which are preferably made of non-conducting materials, and are insulated from one another and provided with a space between them through which the air can circulate freely. In these air spaces there should be no corners or angles liable to retain the air, and allow it to become heated. 3. No air that has passed over metallic parts of the instrument heated by the sun should come in contact with the bulb.

The bulbs of the kite thermographs used at Blue Hill have been screened, as far as possible, according to the principles mentioned above. The experiments with different forms of screens, described on pages 66 and 67, were conducted by Mr. Clayton. The several devices are there explained in detail, in order to show the process of development.

The exposure of the anemometer also requires very careful attention. When the meteorograph is suspended freely in the air, it is seldom at rest, but is moved to and fro, laterally and vertically, by the kites from which it is suspended, because they are influenced by winds of varying intensity. Also, the pressure of the wind upon the instrument itself forces it backward from its vertical position; and, since the wind is often quite variable, the instrument is caused to swing like a pendulum almost constantly. When the instrument is rigidly secured to one of the kites, or to the line below the kites, any change in the angle of incidence or in the position of the kite alters the angle of the instrument with reference to the wind. Such changes in its vertical angle are usually more permanent than any other changes. In addition to these influences, that due to local changes in the direction of the air currents may be mentioned, though probably at high levels this is not marked. Hence, in order to secure a uniform exposure, the instrument should be arranged so as to take its own equilibrium when suspended freely in the air from one of the kites or kite lines. Then the angle of the instrument will remain nearly constant, irrespective of changes in position of the kites; and since a single

suspension is to be preferred on account of safety, the anemometer which presents the smallest obstruction to the wind, and which is least affected by changes in verticality or by changes in direction of the wind, is best adapted for a kite meteorograph. All anemometers requiring a vane to orient them are unsuited to such use because even when fixed in a vertical position they tend to under-register if the horizontal direction of the wind is variable; moreover, when these instruments are suspended from the kites, the effect of sudden gusts in disturbing their verticality would probably cause them to register still less. One advantage of such instruments is that they are more easily protected from injury than others, and possibly a good method of exposing an anemometer of this pattern may yet be devised. Several devices have received consideration, but have not yet been tested. The Robinson cup-anemometer is independent of changes in the direction of the wind, but is affected by changes in the verticality of the instrument which tend to decrease the registration, and perhaps by the pendulum-like oscillations of the instrument which may cause it to over-register. The exact effect of such oscillations has not yet been determined, but the records from a cup anemometer suspended from the kites at the same height as the Observatory anemometers indicate that at moderate velocities this effect is unimportant (see page 94). This form of anemometer is quite simple, and, being easy to construct and to keep in order, it has been adopted for current use. Its principal defect is that the cups, which are placed below the box containing the recording mechanism, are thus subject to damage by collisions with the earth, trees, or buildings.

In Plate VIII. is a photograph of the first Richard thermograph, modified by the writer for use in 1894. The base plate consists of a plate of hard rubber stiffened at the sides by wood. The other parts were made chiefly of aluminium in order to obtain the requisite lightness. The recording mechanism, being of the well known Richard pattern, requires no further description.

In Plate VIII. also are two photographs of the baro-thermo-hygrograph made by M. Jules Richard, and employed since March, 1896; one showing the details of the mechanism, and the other the instrument with protecting cage and suspension cord attached. The instrument, complete, weighs 1.3 kilograms. A cut and description appeared in La Nature of February 8, 1896.

Plate IV. Figure 30 shows the details of the thermo-anemograph employed from November 16, 1895, to June 22, 1896. The pen-arm, *M*, bulb, *K*, and adjusting screw, *L*, form the recording mechanism of the thermograph. The cups, *A*, *A*, and spindle, *B*, of the anemometer, are supported by the tube, *C*, which fits into a casting, *D*, secured to the base plate, *N*, of the instrument. The disk, *P*, at the

top of the spindle, is of hardened steel, and is supported by steel balls contained in the cup *E*, which is also of hardened steel. The bearing at the lower end of the tube *C* is of brass. A thumb-nut, *D*, prevents the cups from dropping off the spindle when in the air. The cups are 2 inches (50.8 millimeters) in diameter, and the distance between their centres and the centre of the spindle is 3.36 inches (85.5 millimeters). Assuming that the cups move with one third of the true velocity of the wind, 1,000 rotations of the cups are made during the passage of one mile of wind. The speed of the cups is reduced by the worm-gearing, *F*, *G*, and *H*, so that one rotation of the wheel *H* is made during the passage of five miles of wind. Into the face of this wheel are inserted five pins, against which the lever *I* rests. This lever is raised successively by the pins as the wheel rotates, causing the arm *J*, which carries the recording pen, to make a short vertical mark on the record cylinder, *O*, for each mile of wind which passes the cups. In Figure 31 is shown another arrangement of the ball bearing at the top of the spindle. In this, the working parts are all below the base plate, *N*, of the instrument, and are thus protected from dust or injury from other causes. The speed of the paper on the drum is four centimeters per hour. All the parts except the spindles, the cup arms, and the bearings, are of aluminium, and the entire instrument weighs 1.2 kilograms. The method of suspending this instrument from the kite line is shown in Figure 32. The lines *E*, *B*, and *C* show respectively the main line and the two cords leading to the kites. From the ring at the junction of the three lines extends a short cord (usually less than four meters long) the lower end of which is secured to the instrument. The heavy parts of the instrument are placed near one end, and the point of support is placed at the same end. A fan or sail, *A*, extends upward from the upper side of the other end of the instrument, and is equal in area to the end of the instrument below the point of suspension. Thus the pressure of the wind is exerted equally above and below the point of suspension, so that when the instrument is forced backward by excessive pressure it still retains an upright position. This instrument and the method of suspension were designed and constructed by the writer.

Figure 33 shows the first method of screening the bulb of the thermo-anemograph. The casing, *S*, of the instrument projects on all sides to a distance of six centimeters below the base plate, *N*. The bulb, *K*, is secured directly to the base plate and is screened from direct sunlight by the projecting casing. While no direct sunlight can fall upon the bulb, the air in the enclosed space surrounding the bulb is liable to become stagnant, and, through contact with the casing, to be heated, thus causing the instrument to record much higher than the true air temperature.

The next experiment was to cut away the projecting edges of the casing, and to surround the bulb with a tubular screen, *R* (Figure 34), which is secured to the base plate, *N*. This screen, while providing a free circulation of air and sheltering the bulb from sunshine, is subject to heat conducted through the base plate to the bulb. The bulb used in the thermo-anemograph is not so sensitive as the bulb in the Richard meteorograph; therefore, on receipt of the latter instrument, in April, 1896, subsequent experiments were made with this instrument. The screen first tried on this instrument was a bag of white muslin slipped over the cage and projecting slightly below the level of the bulb. The position of the lower edge of this cover is shown by the dotted line *G*, in Figure 35. This device was one of the worst tried, because the air confined in the cover rapidly became heated much above the air temperature.

The last device tried is shown in Figures 35 and 36. In the top of the cage surrounding the mechanism are two strips of varnished cloth, *A* and *B*, with a space between them 8 centimeters wide. Under the strip *B*, and on each side of the bulb *D*, are narrow strips of cloth, *C*, *C*, the ends of which are tied to the front and the rear of the cage. These strips are separated from the strip *B* by a space 2 centimeters wide. A fifth strip, *E*, protects the rear of the bulb from direct sunlight. These screens protect the bulb from sunshine and allow the air to circulate freely between the screens and the bulb; moreover, the strips of cloth, being non-conductors of heat, do not transmit to the air around the bulb any heat from the metallic casing which is exposed to the sun. This device, although not considered perfect, is the best that has been tried thus far, and records made by the meteorograph when in the sunshine agree closely with those of the thermograph in the standard shelter of the Weather Bureau (see pages 92 and 93).

In addition to the instruments already described a small baro-thermograph was lent by Professor S. P. Langley, Secretary of the Smithsonian Institution, and was employed in a few flights. This instrument was made by M. Jules Richard for use in balloons at great heights. It is well made, very compact, and weighs but 0.8 kilogram, which is less than any of the instruments employed in the kite experiments. The scale-divisions of this instrument were, however, entirely too small for use in the kite experiments.

NOTE. — November 1, 1897. The experiments described having indicated that the exploration of the air with kites may be extended to greater altitudes, and prosecuted under a greater variety of conditions, preparations have been made for the continuation of the work. To facilitate the use of a greater length of line under long continued strain, a new windlass with a strain-pulley controlled by a steam-engine of two horse-power has been constructed since February, 1897; also a number of important modifications of the meteorographs and accessory apparatus have been made, and tests of some new forms of kites are in progress. On October 15, 1897, the meteorograph was raised to a height of 3,379 meters above the Hill, or 3,559 meters above the Valley.

II. — Results from the Kite Meteorographs and Simultaneous Records at the Ground.

TABLE XVII.

AIR TEMPERATURE AND WIND VELOCITY.

Date and Hour.	Interval in Minutes.	Altitude above Valley.	Air Temperature at Kite.	Air Temperature on Hill.	Air Temperature in Valley.	Humidity on Hill.	Wind Velocity at Kite.	Wind Velocity on Hill.
1894.								
Aug. 4.		*meters.*	° F.	° F.	° F.	*p. ct.*	*m. p. s.*	*m. p. s.*
2:22 P	. .	237	63.2	65.9	68.3	71	. .	4.9
2:41 P	. .	283	63.4	66.8	69.0	69	. .	4.9
3:08 P	. .	332	64.7	69.2	71.2	64	. .	4.5
3:10 P	. .	398	64.7	69.4	71.7	64	. .	5.4
4:37 P	. .	485	65.8	69.1	71.4	63	. .	5.8
4:54 P	. .	max.	64.1	69.7	72.3	62	. .	5.4
5:03 P	. .	616	64.3	69.4	72.3	62	. .	6.7
5:05 P	. .	509	64.4	69.9	72.2	62	. .	7.2
Aug. 15.								
1:30 P	. .	313	72.2	72.7	77.4	73	. .	8.9
1:52 P	. .	386	71.0	72.9	77.4	74	. .	8.0
3:28 P	. .	488	67.5	71.1	73.8	76	. .	6.7
3:30 P	. .	441	67.6	71.0	73.8	76	. .	6.3
4:03 P	. .	300	69.3	71.3	74.1	79	. .	8.9
4:18 P	. .	339	69.4	70.3	72.7	79	. .	8.9
4:20 P	. .	238	69.6	70.1	72.5	79	. .	9.4
1895.								
July 23.								
3:20 P	. .	540	69.0	74.5	77.0	49	. .	7.2
July 29.								
11:53 A	. .	268	73.3	74.8	76.6	47	. .	6.7
11:54 A	. .	273	73.0	74.8	76.8	47	. .	6.7
0:37 P	. .	543	71.0	76.5	77.4	46	. .	7.2
0:38 P	. .	434	72.1	76.5	77.4	46	. .	7.2
0:44 P	. .	512	70.4	75.3	77.0	46	. .	6.7
1:23 P	. .	686	68.3	75.6	78.0	46	. .	6.7
Aug. 19.								
11:15 A	. .	457	71.2	74.0	74.8	59	. .	7.2
11:18 A	2	590	70.0	74.0	74.9	58	. .	6.3
11:34 A	4	464	70.4	74.9	74.8	56	. .	8.0
0:18 P	3	350	70.3	72.7	73.5	59	. .	6.7
1:54 P	5	422	71.1	74.6	75.0	57	. .	5.8
2:27 P	4	570	70.0	76.2	76.8	45	. .	6.7
3:00 P	2	590	69.0	74.2	76.5	44	. .	8.5
3:02 P	1	471	73.3	74.7	76.0	43	. .	9.8
3:28 P	1	634	67.6	73.6	75.5	47	. .	6.3
Aug. 20.								
11:09 A	1	310	64.7	68.8	69.5	48	. .	7.6
11:16 A	2	295	64.5	69.0	70.0	48	. .	7.6
11:18 A	2	373	64.4	69.0	70.0	48	. .	7.6
1895.								
Aug. 20.		*meters.*	° F.	° F.	° F.	*p. ct.*	*m. p. s.*	*m. p. s.*
11:20 A	2	452	62.3	68.8	70.0	48	. .	8.5
11:25 A	1	342	63.8	68.8	70.0	48	. .	8.5
11:35 A	1	311	64.5	68.8	70.2	48	. .	8.5
11:47 A	13	314	64.7	69.6	70.3	48	. .	8.5
0:12 P	13	335	64.2	68.2	68.5	50	. .	7.6
0:19 P	4	380	63.5	67.9	69.2	49	. .	7.6
0:54 P	5	383	65.0	70.0	71.5	50	. .	7.6
1:30 P	. .	342	64.8	68.6	69.0	48	. .	10.3
Aug. 22.								
5:45 P	. .	231	64.2	66.4	64	44	. .	4.5
5:55 P	. .	368	62	66.0	63	45	. .	4.9
5:58 P	. .	384	61	65.8	63	46	. .	4.9
5:59 P	. .	376	61	65.7	62	46	. .	4.9
Aug. 23.								
5:40 P	. .	327	71.5	74.0	72.5	. .	. .	. .
Aug. 24.								
10:50 A	5	297	76.4	79.3	81.8	72	. .	7.6
11:30 A	40	305	77.6	82.3	84.4	65	. .	8.0
0:05 P	6	390	79.3	84.5	85.9	62	. .	8.5
0:20 P	6	441	77.8	84.2	86.5	66	. .	7.6
0:46 P	12	540	77.5	85.7	87.3	61	. .	8.5
1:03 P	. .	483	77.7	84.3	86.9	64	. .	8.5
2:06 P	. .	306	78.0	83.8	86.6	68	. .	10.3
Aug. 26.								
2:59 P	6	231	77.5	77.8	79.0	45	. .	6.3
3:09 P	7	286	76.3	78.5	79.1	44	. .	7.6
3:21 P	6	373	75.1	78.0	78.6	44	. .	8.0
3:32 P	7	355	73.4	77.0	77.9	45	. .	7.6
3:46 P	. .	449	71.3	76.4	76.6	47	. .	7.2
3:57 P	9	546	68.5	75.9	75.9	48	. .	8.0
4:39 P	14	627	67.2	74.3	74.7	54	. .	6.3
4:55 P	10	651	65.8	72.7	74.1	58	. .	5.8
5:05 P	6	664	65.6	72.1	73.3	60	. .	5.8
5:10 P	4	652	65.7	71.9	72.9	61	. .	4.9
5:25 P	8	661	65.8	70.7	72.2	65	. .	4.5
5:32 P	3	587	66.5	70.0	71.4	66	. .	4.9
5:37 P	. .	501	67.8	69.7	71.0	67	. .	4.9
5:41 P	. .	421	68.5	69.6	70.8	69	. .	4.9
5:46 P	. .	352	68.8	69.2	70.4	70	. .	4.9
5:52 P	. .	268	69.6	69.0	70.2	70	. .	4.9

Date and Hour.	Interval in Minutes.	Altitude above Valley.	Air Temperature at Kite.	Air Temperature on Hill.	Air Temperature in Valley.	Humidity on Hill.	Wind Velocity at Kite.	Wind Velocity on Hill.
1895.								
Aug. 27.		meters.	°F.	°F.	°F.	p. ct.	m. p. s.	m. p. s.
2:15 P	8	308	73.9	76.3	79.1	72	. .	. .
2:25 P	6	400	72.3	76.5	79.2	73	. .	6.3
2:53 P	8	395	73.0	77.0	79.6	66	. .	6.7
3:16 P	22	464	71.7	76.8	79.1	65	. .	7.2
3:40 P	. .	416	72.7	76.2	79.3	65	. .	8.0
4:00 P	. .	346	72.5	77.2	79.1	64	. .	8.9
4:37 P	28	270	74.4	74.7	77.0	65	. .	9.8
4:55 P	. .	213	73.2	73.8	75.8	67	. .	8.0
Aug. 28.								
3:50 P	. .	296	83.0	83.8	85.0	56	. .	8.5
4:00 P	. .	339	81.2	84.0	84.8	56	. .	7.2
4:35 P	15	470	77.7	82.9	84.1	56	. .	7.2
4:45 P	10	488	76.8	82.5	83.2	57	. .	8.0
4:55 P	. .	521	76.2	82.1	83.7	58	. .	7.2
5:10 P	5	702	73.8	81.0	82.0	59	. .	7.2
5:20 P	7	695	71.6	80.3	81.1	60	. .	7.6
5:24 P	3	671	71.6	79.9	80.7	60	. .	7.2
5:38 P	7	744	71.1	79.7	79.8	61	. .	6.7
5:50 P	. .	647	71.6	79.2	79.2	62	. .	6.3
5:55 P	. .	588	72.2	79.1	78.8	62	. .	6.3
6:02 P	. .	406	75.0	78.9	78.0	64	. .	6.3
Aug. 31.								
0:05 P	. .	487	68.2	75.0	78.4	59	. .	8.5
0:17 P	. .	552	67.0	75.7	78.5	58	. .	7.2
0:24 P	7	611	66.5	75.1	78.6	61	. .	7.6
0:40 P	. .	587	65.5	74.1	79.9	64	. .	8.5
0:45 P	. .	569	65.6	73.8	78.6	64	. .	8.5
0:49 P	. .	640	65.6	75.3	78.2	65	. .	8.5
0:57 P	. .	627	65.7	76.4	78.8	63	. .	8.5
Sept. 21.								
1:27 P	. .	292	88.9	89.9	91.8	45	. .	6.7
1:41 P	7	363	87.0	89.9	91.9	45	. .	8.5
1:48 P	. .	379	86.3	89.8	92.0	45	. .	8.9
2:08 P	15	497	85.1	89.7	92.2	44	. .	8.5
2:18 P	6	533	84.3	89.9	92.1	44	. .	8.5
2:27 P	7	542	84.1	89.7	92.1	45	. .	7.2
2:44 P	3	658	82.2	90.2	92.1	45	. .	7.6
2:53 P	6	648	82.1	89.9	92.1	45	. .	7.6
3:00 P	. .	625	81.7	89.5	92.0	44	. .	8.5
3:11 P	10	636	81.3	89.0	91.7	45	. .	7.6
4:10 P	. .	195	89.0	. . .	90.6	49	. .	8.5
Nov. 16.								
2:25 P	14	190	. . .	. . .	. . .	46	5.8	6.7
2:39 P	10	325	. . .	. . .	. . .	46	6.7	8.0
3:04 P	. .	384	. . .	. . .	. . .	47	6.3	8.0
3:42 P	. .	504	. . .	. . .	. . .	48	6.7	7.2
1895.								
Nov. 16.		meters.	°F.	°F.	°F.	p. ct.	m. p. s.	m. p. s.
4:05 P	14	504	. . .	. . .	. . .	51	7.2	5.8
4:40 P	16	339	. . .	. . .	. . .	53	6.7	5.4
Nov. 17.								
8:46 A	4	190	43.1	41.8	35.5	87	9.4	8.5
8:56 A	6	268	44.3	42.1	36.0	87	. .	. .
9:32 A	6	413	45.2	42.6	38.0	89	6.3	7.2
9:45 A	5	577	45.0	42.7	39.0	89	. .	. .
9:57 A	6	562	44.2	43.1	39.3	89	7.6	6.3
10:03 A	6	530	44.2	43.1	39.5	89	7.2	5.8
10:15 A	6	413	45.1	43.2	40.0	89	. .	. .
10:26 A	6	277	45.3	43.4	40.5	89	. .	. .
11:04 A	8	190	43.8	44.0	42.5	86	4.5	5.8
Nov. 18.								
3:13 P	15	197	53.5	53.4	55.5	50	6.3	8.0
3:42 P	3	292	52.0	52.8	53.5	52	. .	. .
4:11 P	. .	362	48.5	51.8	52.5	55	. .	. .
4:25 P	11	461	47.3	51.1	52.0	56	8.0	6.7
4:30 P	6	479	47.1	51.0	51.5	56	. .	. .
4:51 P	17	546	45.5	50.8	49.0	58	7.2	7.2
Nov. 19.								
2:25 P	20	267	56.8	58.3	60.0	60	9.8	9.8
2:40 P	12	352	55.0	58.0	60.0	59	8.9	8.9
2:56 P	15	431	53.8	58.0	60.0	58	10.3	8.5
3:47 P	13	500	52.6	56.7	56.5	64	9.4	8.0
3:56 P	6	484	52.5	56.4	56.0	65	. .	. .
Nov. 20.								
1:23 P	9	259	53.6	55.7	58.8	85	. .	. .
1:30 P	6	363	51.8	55.5	58.5	84	9.8	8.5
Nov. 23.								
11:47 A	5	281	43.3	41.9	40.0	75	8.9	5.4
11:55 A	7	285	44.1	42.7	42.5	74	9.4	6.7
0:05 P	8	284	44.3	44.0	43.0	73	10.3	7.2
0:34 P	25	195	49.0	48.8	. . .	69	7.2	8.0
Nov. 25.								
11:17 A	5	195	40.4	40.1	41.8	71	. .	. .
11:31 A	9	302	37.9	40.3	41.8	72	8.0	6.7
11:44 A	5	389	36.5	40.3	41.9	73	8.5	8.0
12:00 A	5	419	35.9	40.3	41.9	77	. .	. .
0:10 P	7	480	35.2	40.3	42.0	78	9.4	7.2
0:24 P	10	573	34.0	40.2	42.0	79	10.7	7.2
0:25 P	1	601	34.0	40.2	42.0	79	. .	. .
0:33 P	8	592	34.0	40.2	42.0	80	10.7	7.2
1:00 P	15	443	38.1	40.1	41.8	87	8.5	6.7
Nov. 27.								
9:37 A	5	220	34.5	36.0	38.8	51	6.7	7.2
10:03 A	10	297	33.5	36.4	40.0	48	5.8	7.2

Date and Hour.	Interval in Minutes.	Altitude above Valley.	Air Temperature at Kite.	Air Temperature on Hill.	Air Temperature in Valley.	Humidity on Hill.	Wind Velocity at Kite.	Wind Velocity on Hill.
1895.								
Nov. 27.		meters.	°F.	°F.	°F.	p. ct.	m. p. s.	m. p. s.
10:43 A	12	413	33.4	37.4	41.5	43	7.6	8.9
11:03 A	9	307	35.4	38.5	42.3	43	8.5	10.3
11:15 A	10	354	35.4	38.8	42.7	43	. .	. .
11:38 A	15	195	39.3	39.3	43.0	40	. .	. .
Nov. 28.								
9:47 A	10	222	34.6	35.0	38.5	64	5.8	4.9
10:10 A	7	320	34.4	35.8	40.0	63	7.2	5.8
10:30 A	6	473	34.1	37.1	40.8	60	7.2	5.8
10:48 A	18	362	35.7	38.0	41.9	59	5.8	4.9
10:55 A	6	337	37.3	38.1	42.0	59	4.5	4.9
Nov. 30.								
9:51 A	10	195	40.0	40.4	43.7	57	6.7	7.6
10:13 A	10	313	37.1	40.3	42.4	58	6.3	8.5
10:35 A	10	403	37.5	40.0	42.1	60	. .	8.5
11:24 A	48	368	35.4	39.3	41.8	61	. .	7.6
11:39 A	10	482	35.2	39.2	41.7	62	. .	8.5
Dec. 9.								
9:12 A	5	192	17.5	17.5	20.4	90	. .	4.9
9:22 A	5	265	18.4	18.0	20.8	90	. .	5.4
9:32 A	5	198	18.0	18.1	21.2	89	. .	4.9
9:46 A	5	270	17.4	18.3	21.6	89	. .	5.4
9:56 A	8	318	25.2	18.5	21.7	88	. .	4.9
9:59 A	. .	268	21.9	18.6	21.8	88	. .	4.9
10:00 A	. .	243	20.7	18.7	21.9	88	. .	4.9
Dec. 10.								
9:52 A	13	230	. . .	. . .	. . .	64	5.4	5.4
10:31 A	5	482	18.4	20.7	23.5	55	4.9	5.4
Dec. 12.								
10:10 A	13	195	6.6	6.6	9.7	65	9.4	9.4
10:30 A	15	299	6.7	4.5	9.6	65	9.4	8.5
10:45 A	. .	299	7.7	6.6	10.7	65	9.4	8.5
Dec. 21.								
2:18 P	6	207	54.9	55.3	50.9	69	. .	8.0
2:26 P	7	282	53.7	54.8	50.0	69	. .	7.6
2:40 P	11	386	51.9	54.5	49.7	69	8.0	6.3
2:56 P	12	473	50.6	54.2	49.0	69	8.9	6.3
3:12 P	14	540	49.7	54.1	49.0	69	9.8	6.7
3:30 P	15	614	48.6	54.0	48.5	70	10.3	6.7
4:14 P	11	399	51.5	53.2	47.7	76	10.3	6.7
4:26 P	6	269	52.7	52.7	47.0	78	10.3	8.0
4:47 P	16	191	52.0	52.3	46.8	78	8.5	8.5
Dec. 25.								
4:45 P	18	357	38.9	41.6	44.0	72	5.4	4.9
Dec 26.								
4:05 P	11	302	50.5	51.5	53.1	97	12.0	10.3

Date and Hour.	Interval in Minutes.	Altitude above Valley.	Air Temperature at Kite.	Air Temperature on Hill.	Air Temperature in Valley.	Humidity on Hill.	Wind Velocity at Kite.	Wind Velocity on Hill.
1896.								
Jan. 12.		meters.	°F.	°F.	°F.	p. ct.	m. p. s.	m. p. s.
10:47 A	. .	195	23.0	23.0	13.8	66	. .	7.2
10:50 A	. .	262	24.3	23.2	14.3	66	. .	7.2
Jan. 13.								
2:45 P	3	280	26.3	27.6	29.5	43	. .	7.2
2:59 P	5	347	24.7	27.4	29.3	43	. .	7.2
3:08 P	3	337	24.1	27.3	29.1	44	. .	6.7
3:18 P	5	461	22.2	27.1	29.0	45	. .	5.4
3:20 P	. .	480	22.8	27.1	28.8	45	. .	5.8
3:30 P	12	596	21.9	27.0	28.5	45	. .	6.7
3:32 P	2	620	19.9	26.9	28.4	45	. .	6.3
3:41 P	6	621	19.6	26.8	28.2	45	. .	5.8
3:42 P	1	669	19.3	26.7	28.2	45	. .	5.8
3:59 P	3	488	21.2	26.7	28.1	45	. .	6.7
4:06 P	2	449	21.8	26.5	27.9	45	. .	6.7
4:13 P	3	356	23.8	26.3	27.6	45	. .	6.7
4:20 P	3	257	25.4	26.1	27.3	45	. .	. .
Jan. 17.								
11:36 A	8	352	26.6	30.4	34.4	50	. .	6.7
11:45 A	6	444	24.3	30.6	34.3	51	. .	6.7
12:00 A	11	505	24.0	30.5	34.4	51	. .	4.9
0:07 P	7	517	23.7	30.5	34.6	51	. .	4.0
0:15 P	. .	440	24.8	30.6	34.7	52	. .	6.3
0:17 P	. .	391	25.3	30.7	34.6	51	. .	6.3
0:22 P	. .	260	28.8	30.8	34.6	51	. .	4.9
Jan. 18.								
11:06 A	17	373	21.9	24.8	27.8	90	. .	9.4
11:17 A	. .	263	23.5	24.9	28.1	89	. .	7.6
3:22 P	4	345	25.1	27.7	30.2	75	. .	5.8
3:42 P	17	425	23.4	27.3	29.9	77	. .	6.7
3:51 P	9	497	21.4	27.3	29.8	78	. .	7.6
4:16 P	17	582	19.3	26.8	29.0	79	. .	6.7
4:19 P	2	583	19.3	26.8	28.8	79	. .	6.7
4:26 P	6	506	21.5	26.6	28.7	79	. .	6.7
4:39 P	7	337	23.6	26.2	28.4	80	. .	6.7
Jan. 27.								
2:20 P	9	195	29.1	29.4	32.6	58	10.3	9.3
2:39 P	16	356	26.1	29.9	32.6	57	10.7	10.3
3:00 P	10	508	24.5	30.3	32.6	57	. .	10.3
3:17 P	15	558	23.8	30.2	32.8	57	9.8	10.3
3:26 P	9	584	22.7	30.2	32.9	57	8.0	9.8
3:33 P	7	558	23.2	30.3	33.4	56	10.3	10.3
3:57 P	11	361	27.1	30.1	33.6	56	. .	10.3
4:19 P	16	198	29.9	29.9	33.0	57	9.4	9.8
Jan. 28.								
5:29 P	10	220	19.2	19.6	20.6	42	8.5	8.5
5:50 P	14	339	17.5	19.2	20.4	42	12.1	10.3
6:01 P	6	256	18.5	18.9	20.3	42	11.6	10.3

Date and Hour.	Interval in Minutes.	Altitude above Valley.	Air Temperature at Kite.	Air Temperature on Hill.	Air Temperature in Valley.	Humidity on Hill.	Wind Velocity at Kite.	Wind Velocity on Hill.
1896. Jan. 30.		*meters.*	°F.	°F.	°F.	*p. ct.*	*m. p. s.*	*m. p. s.*
1:10 P	11	195	28.8	28.7	32.0	68	7.6	8.0
1:25 P	12	367	25.6	29.3	32.7	67	7.6	7.6
1:47 P	12	590	23.0	30.0	33.3	65	8.5	6.7
2:10 P	11	330	28.8	31.0	34.9	62	7.2	7.2
2:26 P	11	195	31.8	31.8	35.0	61	5.8	6.7
Feb. 3.								
10:04 A	3	217	20.1	20.4	24.2	71	. .	. .
1:16 P	10	334	21.7	25.9	28.8	85	6.3	5.8
Feb. 8.								
5:29 P	16	491	29.7	33.9	35.5	49	8.5	7.2
5:48 P	6	351	31.2	33.3	34.9	50	7.2	7.2
Feb. 10.								
5:15 P	11	383	26.5	28.8	31.3	53	11.6	9.4
5:25 P	4	545	23.7	28.8	31.1	53	13.0	9.8
5:45 P	10	342	26.5	28.6	30.9	54	11.6	8.5
Feb. 12.								
5:21 P	11	390	22.3	25.4	27.9	50	8.9	8.5
5:34 P	10	562	18.5	25.1	27.3	50	9.4	8.9
5:40 P	6	578	18.3	24.8	27.1	50	9.8	8.5
5:55 P	6	387	20.8	24.5	26.6	50	9.4	7.6
Feb. 13.								
2:25 P	7	311	28.3	28.2	31.4	100	11.6	8.5
2:30 P	6	311	. . .	. . .	. . .	100	13.4	8.5
Feb. 17.								
4:20 P	8	476	−0.9	2.6	6.7	44	. .	9.4
4:40 P	6	525	−4.5	2.8	6.5	44	. .	7.2
4:57 P	8	325	−0.2	2.7	6.0	45	. .	8.0
Feb. 18.								
2:40 P	. .	300	15.9	18.1	21.6	91	. .	6.7
2:49 P	8	362	15.2	18.7	22.2	85	. .	5.8
3:04 P	10	520	13.7	20.7	23.6	82	. .	10.7
3:21 P	7	357	16.6	20.8	23.7	82	. .	8.5
3:32 P	5	198	20.0	20.9	24.0	77	. .	8.5
Feb. 19.								
5:14 P	3	197	27.2	27.3	29.0	61	. .	7.6
5:25 P	6	313	26.0	26.9	28.6	61	. .	8.5
Feb. 22.								
4:45 P	4	348	20.7	24.4	27.2	44	. .	9.4
4:52 P	4	494	17.2	24.4	27.1	44	. .	9.4
5:00 P	4	594	16.7	24.3	26.7	44	. .	11.6
5:07 P	2	637	16.3	24.2	26.4	44	. .	11.6
5:42 P	. .	355	21.1	23.4	25.4	46	. .	10.3
5:55 P	. .	291	22.2	23.3	25.1	46	. .	8.9
Feb. 23.								
2:50 P	6	357	39.7	42.3	40.9	45	. .	8.9
3:03 P	9	473	37.9	42.3	42.2	46	. .	8.9

Date and Hour.	Interval in Minutes.	Altitude above Valley.	Air Temperature at Kite.	Air Temperature on Hill.	Air Temperature in Valley.	Humidity on Hill.	Wind Velocity at Kite.	Wind Velocity on Hill.
1896. Feb. 23.		*meters.*	°F.	°F.	°F.	*p. ct.*	*m. p. s.*	*m. p. s.*
3:15 P	. .	601	40.9	42.1	41.0	47	. .	9.4
3:45 P	. .	500	38.9	43.3	41.6	47	. .	8.9
4:03 P	. .	545	37.7	42.7	41.7	49	. .	8.9
Mar. 6.								
5:30 P	15	192	. . .	. . .	. . .	58	4.5	4.5
5:50 P	11	264	30.8	31.2	31.8	61	6.3	4.9
5:58 P	4	233	31.9	30.9	31.4	61	. .	5.8
6:02 P	3	223	32.4	30.8	30.8	62	. .	5.8
6:05 P	. .	294	33.3	30.5	30.5	62	. .	5.8
Mar. 10.								
2:05 P	10	255	30.0	32.0	34.6	43	. .	5.4
2:45 P	. .	342	31.5	33.6	35.5	42	. .	4.5
2:47 P	. .	428	29.0	33.7	35.5	42	. .	4.5
2:55 P	8	269	30.4	33.4	35.8	42	10	4.5
3:03 P	4	337	30.3	33.1	36.4	42	. .	5.8
Mar. 11.								
11:03 A	. .	352	28.7	30.3	32.2	85	. .	10.3
11:26 A	10	323	28.2	30.5	32.7	86	10.3	8.9
11:33 A	6	377	27.4	30.5	32.7	86	10.7	9.8
11:50 A	6	452	25.8	30.6	32.7	86	. .	10.7
12:00 A	7	573	24.0	30.6	32.6	87	. .	11.6
0:16 P	15	622	23.2	30.6	32.0	87	. .	11.2
0:35 P	6	739	21.9	30.3	30.8	95	. .	10.7
Apr. 5.								
4:12 P	6	267	38.5	40.7	43.0	40	8.9	10.7
4:26 P	8	506	33.2	40.3	42.3	42	8.9	8.5
4:44 P	5	642	30.7	39.9	41.0	44	8.0	9.8
5:12 P	10	795	29.7	39.5	41.8	46	8.0	9.4
5:25 P	9	697	29.4	39.4	41.0	48	7.6	8.5
5:50 P	10	753	28.3	38.3	40.5	50	8.5	8.0
6:01 P	4	778	27.1	37.8	39.7	51	8.9	8.0
6:18 P	8	624	29.8	37.0	39.0	53	9.4	8.0
6:24 P	4	548	30.9	36.8	38.6	54	9.4	8.5
6:35 P	6	376	33.7	36.6	38.3	55	9.4	8.9
Apr. 7.								
3:12 P	6	286	31.1	33.0	37.0	63	. .	7.6
3:27 P	8	382	28.1	32.0	35.8	70	. .	7.6
3:33 P	4	472	26.5	31.8	35.7	70	. .	7.2
3:36 P	. .	540	24.8	31.8	35.7	70	. .	6.7
5:25 P	20	778	20.6	31.1	34.9	71	. .	6.7
Apr. 13.								
9:22 A	15	271	55.9	58.6	61.6	59	9.8	11.2
9:30 A	6	360	56.0	59.1	62.3	57	12.1	10.3
9:45 A	4	517	71.2	60.6	63.6	55	. .	8.9
10:12 A	20	680	71.5	63.1	67.5	53	13.4	10.3
10:49 A	34	748	69.6	67.6	70.7	48	14.8	8.9

Date and Hour.	Interval in Minutes.	Altitude above Valley.	Air Temperature at Kite.	Air Temperature on Hill.	Air Temperature in Valley.	Humidity on Hill.	Wind Velocity at Kite.	Wind Velocity on Hill.
1896.								
Apr. 13.		meters.	° F.	° F.	° F.	p. ct.	m. p. s.	m. p. s.
11:05 A	12	927	68.2	69.6	72.1	45	15.6	9.4
11:16 A	7	1005	67.1	70.8	72.8	44	15.6	8.5
11:38 A	18	954	66.0	73.3	75.0	42	15.2	8.0
0:08 P	6	686	70.0	75.6	78.0	40	11.6	7.6
0:18 P	5	412	69.4	76.2	78.9	40	8.5	7.6
0:29 P	4	384	73.4	77.3	79.5	39	. .	7.6
0:33 P	3	473	73.4	77.8	79.5	39	8.9	8.0
0:36 P	3	402	73.2	77.9	79.7	38	. .	8.0
0:38 P	2	564	73.3	78.0	79.9	38	. .	8.5
0:50 P	5	339	76.2	78.3	81.0	38	. .	8.9
1:10 P	11	215	79.5	79.3	81.7	36	8.9	8.5
Apr. 18.								
4:57 P	3	312	71.2	72.1	. .	47	5.4	5.4
5:30 P	. .	232	68.5	63.1	64.2	79	7.2	7.2
Apr. 20.								
4:45 P	. .	240	70.0	71.0	73.0	27	. .	. .
4:48 P	. .	264	70.0	70.9	73.0	27	12.1	13.4
May 19.								
4:57 P	7	492	56.2	59.6	63.4	. .	9.4	7.2
5:05 P	4	679	53.4	59.7	63.2	. .	9.4	6.3
5:16 P	2	543	55.6	59.5	62.8	. .	. .	6.3
May 20.								
3:48 P	7	461	56.7	57.0	61.5	62	9.4	9.4
4:17 P	15	734	56.7	56.8	61.3	57	8.0	8.9
4:32 P	6	834	51.7	55.7	59.3	54	6.7	10.7
4:55 P	10	780	52.7	55.0	57.9	54	6.7	9.8
June 18.								
5:02 P	4	365	66.7	70.8	77.1	74	7.2	6.7
5:14 P	4	407	66.3	71.5	77.1	75	6.7	5.8
5:21 P	5	578	65.1	71.2	76.9	77	. .	. .
5:40 P	8	765	63.0	70.8	76.5	81	8.0	5.4
5:45 P	3	743	63.1	70.7	76.0	82	. .	. .
6:00 P	7	587	65.8	68.6	75.0	85	8.5	6.3
6:06 P	2	419	66.1	68.4	75.1	86	. .	. .
6:16 P	5	366	65.9	68.2	74.7	86	6.7	5.4
6:20 P	. .	206	66.1	68.1	74.4	86	5.4	5.4
June 19.								
2:30 P	. .	328	81.1	85.0	86.9	37	. .	5.4
2:39 P	3	526	75.8	84.8	86.7	38	. .	. .

Date and Hour.	Interval in Minutes.	Altitude above Valley.	Air Temperature at Kite.	Air Temperature on Hill.	Air Temperature in Valley	Humidity on Hill.	Wind Velocity at Kite.	Wind Velocity on Hill.
1896.								
June 19.		meters.	° F.	° F.	° F.	p. ct.	m. p. s.	m. p. s.
2:42 P	3	492	76.3	84.6	86.7	38	. .	. .
2:44 P	1	581	75.3	84.7	86.6	38	. .	. .
2:47 P	3	492	76.0	84.7	86.6	38	. .	. .
2:50 P	3	545	75.6	84.6	86.6	38	6.7	6.3
3:03 P	6	693	72.7	84.4	86.6	39	. .	. .
3:07 P	3	572	75.0	84.4	86.1	39	. .	. .
3:11 P	3	665	73.7	84.6	85.9	40	6.3	5.8
3:24 P	3	1000	66.4	84.5	85.9	42	. .	. .
3:34 P	8	905	68.2	84.2	86.0	42	6.7	5.4
3:42 P	3	805	70.1	84.2	86.1	43	. .	. .
3:48 P	6	882	66.8	84.3	86.2	44	. .	. .
3:57 P	4	1023	65.7	84.0	86.2	44	. .	. .
4:06 P	8	1057	65.4	84.5	86.1	45	7.2	6.3
4:11 P	5	1014	66.0	83.3	86.0	45	. .	. .
4:17 P	6	1075	65.2	83.3	85.9	45	. .	. .
4:24 P	6	1045	65.5	83.3	85.7	45	7.2	6.3
4:25 P	1	1098	64.7	83.3	85.7	45	. .	. .
4:26 P	. .	1101	64.5	83.3	85.7	45	. .	. .
4:30 P	5	1103	64.7	83.2	85.7	45	. .	. .
4:45 P	4	902	68.5	82.8	85.2	44	. .	. .
4:55 P	. .	856	72.2	82.7	85.2	44	. .	. .
5:13 P	11	537	75.1	82.5	85.1	44	7.2	5.4
June 20.								
5:39 P	3	402	79.3	81.3	82.4	54	. .	. .
5:48 P	9	396	79.4	81.3	81.0	54	8.0	5.4
6:03 P	10	572	75.9	80.8	81.8	56	8.9	5.4
6:14 P	5	398	78.9	80.7	80.9	57	7.2	5.4
June 22.								
3:41 P	15	360	76.8	79.6	83.6	34	11.6	10.3
4:10 P	35	527	73.9	80.1	82.9	38	12.1	10.3
4:31 P	14	680	71.3	79.6	82.3	39	11.6	9.4
5:15 P	15	926	65.8	77.8	80.6	45	12.5	8.9
5:32 P	7	1024	63.9	77.8	80.8	46	12.5	9.8
5:44 P	3	1094	65.8	77.5	80.5	47	. .	. .
7:00 P	60	1062	. .	. .	. .	. .	11.2	7.6
7:43 P	10	1072	63.2	72.4	73.2	62	10.3	8.9
8:25 P	29	863	65.5	71.7	72.5	62	12.1	9.4
8:57 P	5	768	69	71.2	72.2	63	. .	9.8
9:45 P	8	646	69	70.1	70.8	67	. .	9.4
9:55 P	. .	480	69	69.2	69.8	68	. .	8.5

NOTE. — The second column gives the length of the interval, ending with the time given in the first column, that the meteorograph remained near the same altitude. The third column gives the mean altitude during this interval. The fourth column gives the temperature recorded by the meteorograph at the end of the interval and at the time given in the first column. The eighth column gives the mean wind velocity recorded by the kite meteorograph during the interval given in the second column. The remaining columns give synchronous observations at the ground.

REMARKS.

1894.

August 4. Cloudy during the morning with strato-cumulus surmounted by a sheet of alto-stratus, but these began to break away about 2 P. M., though the sky continued more than half covered. Temperature below normal. Wind WSW veering to W.

August 15. The sky was covered with alto-cumulus and alto-stratus increasing in density, and it became necessary to draw down the kites on account of the approach of a thunder-shower from the west which reached the Observatory at 5:14 P. M. Temperature normal. Wind SSW backing to S.

1895.

July 23. Weather fair. Sky partly covered with cirro-stratus and alto-stratus. Temperature above normal, but falling. Wind NW.

July 29. At the time of the ascent cumulus clouds were passing overhead and the wind was very gusty. As each cumulus approached the hill the kites rose rapidly, going up sometimes 100 or 150 meters in a minute, and falling as quickly. About 1:50 P. M. the cord broke, and three kites and the thermograph were carried about three miles in the next five minutes. They were recovered about 5 P. M., and were found to be not seriously damaged. Temperature near normal. Wind W veering to WNW.

August 19. Weather fair. Sky partly covered with cirro-stratus, and a few fracto-cumulus changing later to strato-cumulus. Temperature slightly above normal. Wind W.

August 20. Sky partly covered with alto-cumulus, cumulus, and strato-cumulus, followed during the evening by cumulo-nimbus. Between 11:16 and 11:19 A. M. the kites rose rapidly towards the zenith, and reached the greatest angle above the horizon observed during the day (65°), and at the same time a small cumulus cloud began to form immediately above them. The observations indicate a rise of the kites of about 600 feet in three minutes. Cool wave on the 21st. Wind WSW.

August 22. Clear weather during the flight except a few cirrus. Cumulus observed earlier in the day. Stratus formed during the night of the 22d. Very cool in the early morning of the 22d. Wind SW.

August 23. Sky nearly clear at the time of the flight. Temperature rising rapidly.

August 24. Warm wave. Sky partly covered by cirro-cumulus, alto-cumulus, and cumulus, followed during the evening by cumulo-nimbus. Wind SSW backing to S.

August 26. The sky was clear, excepting a few cirrus and fracto-cumulus. Twice, after rapidly ascending currents which carried the kites upward, small cumulus clouds were observed to form near the zenith. Wind WSW backing to S.

August 27. Sky partly covered with alto-stratus and alto-cumulus. Between 3 and 3:30 P. M. the kites along the line formed a well defined curve. The lower kites were from the SW, and the upper kites from nearly W.

August 28. Sky partly covered with alto-cumulus and cumulus. Very warm, followed by a cool wave on the 29th. Wind WSW.

August 31. Sky partly covered with alto-cumulus and strato-cumulus. Wind S. Thunderstorm in evening.

Sept. 21. Exceptionally warm for September, the temperature recorded on the 21st, 22d, and 23d being the highest in September for many years. The sky remained entirely clear excepting for a few cumulus during a part of the day. Wind W.

Nov. 16. Sky partly covered with cirrus. A thermo-anemograph was used for the first time, and a record of wind velocity obtained. The record of temperature was lost. Wind W backing to WSW.

Nov. 17. Sky covered with a sheet of alto-stratus, which was soon followed by nimbus, fog, and rain. Wind SE.

Nov. 18. Sky partly covered with cirro-cumulus. Temperature rising rapidly. Warm wave approaching. Wind W and WSW.

Nov. 19. Sky clear, excepting a few cirro-cumulus. Warm for the time of year. Wind S.

Nov. 20. Weather cloudy. Sky nearly covered with alto-stratus and low strato-cumulus clouds. Cold wave during the night of the 20th and on the 21st. Wind SSW.

Nov. 23. Sky partly covered with cirrus, cirro-cumulus, and cumulus. Flight made near the crest of a warm wave. It was difficult to begin the ascent on account of the light winds below, but as soon as the kites ascended a few hundred feet the wind was so strong that they were driven down and it was impossible to get higher. At the beginning of the ascent low fracto-stratus or scud clouds were drifting rapidly across the sky. The kites entered and temporarily disappeared in these clouds at an altitude of about 60 meters above the hill. The lower wind was light, and came alternately from the northwest and from the south, increasing in velocity to 4 or 5 meters a second when from the south, and diminishing to 2 or 3 when from the north. Above the hill during the entire morning preceding the ascent, the scud clouds were drifting rapidly from the south. This southerly current descended below the level of the hill during the ascent, the scud clouds disappeared, and, later, cumulus began to form. Cold wave followed on the morning of the 24th.

Nov. 25. Sky covered with strato-cumulus clouds, which grew gradually lower and light rain began at 12:35 P. M. The kites were brought down during a light drizzle. Wind ESE veering to E. The kites veered 20° or more of azimuth to the right as they rose.

Nov. 27. Storm passed off the New England coast during the night. Sky clear except for a few cirrus and fracto-cumulus. Temperature near normal, but decidedly lower than on the 26th. Wind NW.

Nov. 28. Sky clear except for a few scattered cirrus. Wind W.

Nov. 30. Sky partly covered by cirro-stratus and alto-cumulus, followed by clearing weather. About 11:38 A. M. the wind suddenly increased in velocity with the oncoming of

a cold wave, and the kites were driven to the ground without seriously injuring the instrument. The record of the meteorograph and the behavior of the kites at the beginning of the ascent indicated that the wind velocity diminished with altitude. At this time the weather was partly cloudy and threatening, with dense sheets of high alto-stratus having cirriform edges. Later the sky began to clear, and the kite anemometer showed that the wind velocity increased very much aloft. This increase aloft preceded a like increase below by about 40 minutes.

Dec. 9. Sky covered with stratus, or low strato-cumulus, moving from the east. The kites left the ground in a northerly wind. At a height of about 270 meters they suddenly entered a strong easterly current above, and were soon partly obscured by the stratus cloud into which they entered.

Dec. 10. Sky partly covered with a sheet of cirro-stratus. Cold wave on the 11th. Wind NNW.

Dec. 12. Sky nearly covered with low strato-cumulus. Temperature very low. Wind N. Warmer on 13th.

Dec. 21. Sky nearly covered with high strato-cumulus. Very warm for the time of year. Wind ESE.

Dec. 25. Sky covered with high strato-cumulus. Wind SE.

Dec. 26. Sky covered with low strato-cumulus and nimbus. Rain began at 4:15 P. M. Wind SSE.

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Jan. 12. Sky nearly covered with a sheet of alto-stratus; cyclone centre approaching; minimum barometer with rain in the afternoon; wind south and increased rapidly with altitude. A warm wave with crest in afternoon.

Jan. 13. Sky partly covered with cirrus. Temperature falling rapidly. Wind W veering to WNW, and its velocity decreasing from 9 to 7 meters per second.

Jan. 16. Sky clear except for a few cirro-cumulus. Kite meteorograph sent to an altitude of 1,824 meters, but no record obtained.

Jan. 17. Sky covered with cirro-stratus densest in the southwest. Storm central near Hatteras. Temperature reached a maximum in the afternoon. Wind NNE veering to NE. Kites shifted to the right as they ascended.

Jan. 18. The thermograph left the ground during a light snow. At 10:50 A. M. the thermograph entered the base of the nimbus. At 11:10 A. M. the thermograph and kites were drawn out of and below the cloud. On reaching the ground, the thermograph and kites, and about 100 feet of line, were found heavily coated with frost work. During the second flight, which was made in the afternoon, the snow had ceased, but the sky continued covered with low clouds. At 4 P. M. the thermograph entered the base of the cloud and remained in the cloud until 4:16 P. M. Temperature fell during the day. Wind N veering to NNE.

Jan. 27. Steel wire first used for the kite line. Sky clear. Temperature considerably below normal, and reached a minimum at night. Wind NW.

Jan. 28. Weather clear; temperature decidedly below normal; the minimum temperature of the cold wave occurred on the night of the flight. Wind NW.

Jan. 30. Sky partly covered with dense cirro-stratus, which entirely cleared away by evening. Temperature near normal. Wind WNW.

Feb. 3. Sky covered with dense alto-stratus and low strato-cumulus or nimbus; light scattered flakes of snow falling during the flight. Wind NE.

Feb. 8. Sky clear during the flight except for a few scattered cirrus. A few fracto-cumulus observed in the early afternoon. Temperature above normal but falling. Wind W.

Feb. 10. Sky clear except for a few strato-cumulus. Temperature near normal. Wind WNW.

Feb. 12. Sky clear except for a few fracto-cumulus. Temperature below normal. Wind W.

Feb. 13. Kites sent up during a southeast storm. Snow was falling shortly before the ascent, but this changed to sleet and rain about the time of the ascent and these continued to grow gradually heavier. The kites were driven down by the high wind above, and on reaching the ground were found to be coated with ice. The kites entered the base of the nimbus when about 30 meters of line was out, and soon became invisible. Wind SE; kites from SSE.

Feb. 17. Temperature extremely low. The lowest temperature for ten years was recorded in the early morning. Sky clear except a few strato-cumulus on the east horizon. The first atmospheric electricity observed on the wire was noted to-day. At the highest point the potential was sufficient to cause the spark to pass through woollen mittens. Wind NW backing to WNW.

Feb. 18. The sky was covered with nimbus and light snow was falling during the flight. At 2:45 P. M. and with an altitude of 358 meters a fracto-nimbus obscured the kites and instrument for about half a minute. The sun was dimly visible from 2:47 to 2:55 P. M. Between 2:55 and 3:04 P. M., at a height of 520 meters, fracto-nimbus were occasionally drifting under the kites, but the main cloud sheet was higher. Temperature decidedly below normal, but rising. Wind NE veering to ENE. Kites shifted to the right, passing through an ENE into an E wind as they ascended.

Feb. 19. Sky clear except for a few cirrus. Temperature below normal, but warmer than on the preceding and following days. Wind SE backing to ESE.

Feb. 22. A new reel and register were finished yesterday, and to-day 1,600 meters of new music wire were wound on, in addition to the 640 meters previously obtained. Ascent begun at 4:37 P. M. Weather clear except for a few cirro-stratus. Temperature below normal but rising. Wind WSW veering to W.

Feb. 23. Sky nearly covered with alto-stratus which rapidly increased in density, and light sprinkles of rain fell between 4 and 4:18 P. M. Temperature above normal, due to the approach of a warm wave. In hauling in the kites, the pressure of the wire forced the drum-heads of the reel apart. Wind SSW.

March 6. Sky covered with alto-stratus increasing in density, and followed by rain on the early morning of the 7th. Temperature near normal. At 6:04 P. M. the kites shifted suddenly from the southeasterly wind below into a southerly wind above. A belt of light winds was found between the two currents. Wind SE veering to SSE. Kites from S at the highest point.

March 10. Sky covered with a sheet of cirro-stratus. Temperature near normal.

March 11. At the beginning of the ascent the sky was covered with nimbus, and a severe storm was approaching from the southwest. Snow began at 11:55 A. M. At 11:56 A. M. the kites entered a fracto-nimbus at an altitude of 580 meters. At 0:25 P. M. the kites entered the main body of the nimbus at an altitude of 723 meters. At 0:02 P. M. electric sparks could be drawn from the line, and very soon they became so strong that it was necessary to ground the line. Began to haul the kites in at 1:06 P. M. By this time it was snowing hard. Strong electric shocks were felt whenever the ground wire was accidentally removed. The wind increased to more than fourteen meters per second, and the pull was so great that four men were nearly exhausted in winding the line in. When the wire was wound in to the upper 1,000 meters which had entered the cloud, the wire was found to be thickly coated with frost or fine snow, which fully doubled its diameter. At 2:20 P. M., while winding at the rate of about 0.4 meter per second, the wind increased to about 16 meters per second (corrected to true velocity), and the wire parted near the instrument and the kites, all of which were carried away, but were afterwards recovered. Temperature near normal, but there was a cold wave on the 12th. The clock cylinder was clogged and stopped by the snow about 0:40 P. M. The wind was from the E during the flight, and the kites continued to pull from the E at the highest point reached.

April 5. The sky was nearly covered with strato-cumulus during the flight, but the sun shone on the instrument at intervals. Temperature below normal, but higher than on the preceding and following days. Wind NW.

April 7. The sky was nearly covered with massive strato-cumulus, from which occasional light snow fell during the flight. At the end of the flight alto-cumulus were seen above. Temperature decidedly below normal. Wind NE.

April 13. Sky clear during the first flight. Temperature above normal, and rising rapidly at the ground. Electricity became strong when an altitude of 942 meters was reached, and was strongly felt at the highest point. In ascending the kites suddenly shifted from west-southwest to west wind, at an altitude of 524 meters, and in descending suddenly shifted from west to west-southwest wind at an altitude of 470 metres. Wind WSW.

April 18. Sky nearly covered with a sheet of cirro-stratus. Sea breeze set in while the kites were in the air, and the temperature fell rapidly at the ground.

April 20. Sky partly covered with cirrus. Temperature decidedly above normal; a cool wave on the 21st. Wind W.

May 20. Sky nearly covered with cirro-stratus. Wind SSW; kites from SSW at highest point.

June 18. Sky clear except for a few cumulus. Temperature above normal and rising rapidly, due to the approach of a warm wave. Slight shocks of electricity were received from the line after the kites reached an altitude of 400 meters. Wind S and SSW; kites from NW above 500 meters.

June 19. Sky clear except for a few scattered cumulus and cirro-stratus. Temperature decidedly above normal and rising slowly. A cumulus passed the zenith between 3:22 to 3:24 P. M., and drew the kites up to a steep angle. Wind W backing to WSW.

June 20. Sky partly covered with cumulus and cumulo-nimbus. Temperature continued decidedly above normal. Wind WSW.

June 22. Sky about half covered with cirro-stratus. Temperature above normal but falling rapidly. Wind W veering to WNW and NW.

NOTE. — The direction of the wind is that of the surface wind on Blue Hill, and the altitudes are above the Valley Station, 180 meters below the summit of the Hill, unless otherwise stated.

TABLE XVIII.

AIR TEMPERATURE AND RELATIVE HUMIDITY.

Date and Hour.	Interval in Minutes.	Altitude above Valley.	Air Temperature at Kite.	Air Temperature on Hill.	Air Temperature in Valley.	Humidity at Kite.	Humidity on Hill.	Wind Velocity on Hill.
1896. April 8.		meters.	° F.	° F.	° F.	p. ct.	p. ct.	m. p. s.
4:00 P	15	355	31.5	35.7	38.9	36	40	8.5
4:04 P	3	445	31.0	35.7	38.6	35	41	8.0
4:13 P	5	578	29.4	35.5	38.4	35	41	7.2
4:25 P	5	743	27.2	35.2	38.3	36	42	7.6
4:37 P	5	930	24.3	35.0	38.2	34	42	7.2
4:44 P	4	887	24.9	35.0	37.8	32	42	7.2
5:03 P	6	384	31.5	35.2	37.8	36	40	6.7
April 11.								
3:55 P	25	296	52.5	55.5	58.6	52	50	9.4
4:13 P	5	437	52.6	55.5	58.4	54	50	8.5
4:25 P	7	480	51.0	55.2	57.1	57	51	7.6
4:32 P	3	540	47.8	54.5	57.0	61	52	8.9
4:42 P	5	603	46.6	54.3	56.8	63	52	8.0
5:03 P	12	814	42.2	53.5	56.3	74	52	8.5
5:20 P	5	673	43.2	52.7	55.5	74	53	8.5
5:30 P	2	564	44.6	52.5	55.4	71	53	7.2
5:34 P	4	483	45.8	52.5	55.3	68	53	6.7
5:45 P	3	372	47.8	52.4	55.0	66	54	6.7
April 13.								
3:37 P	4	329	77.0	81.2	83.9	39	35	7.2
3:54 P	6	528	74.3	81.2	83.7	42	35	7.6
4:16 P	12	695	71.7	80.2	81.6	45	37	8.0
4:25 P	4	742	69.4	79.5	81.5	45	37	7.6
4:43 P	5	899	67.4	79.3	81.3	47	37	6.3
5:23 P	4	1060	65.4	77.8	77.4	45	40	7.2
5:28 P	4	1221	64.4	77.6	76.8	46	42	6.7
5:32 P	3	1370	62.0	77.1	76.5	45	42	7.6
5:38 P	4	1336	62.6	75.9	75.1	44	42	6.7
6:02 P	6	1089	66.9	73.3	72.6	42	46	4.9
6:20 P	6	891	68.5	72.8	70.5	43	48	5.8
6:35 P	2	620	72.5	71.6	68.7	43	48	5.4
6:50 P	7	401	72.1	71.2	67.6	43	49	6.3
7:02 P	5	227	70.8	70.3	67.0	49	50	6.3
April 15.								
4:54 P	6	208	76.2	76.9	78.2	37	37	6.3
5.06 P	6	277	76.6	76.1	77.0	39	38	6.3
5:24 P	4	294	76.2	74.1	75.9	43	42	5.4
5:49 P	10	384	73.7	72.5	72.8	41	46	5.8
5:54 P	5	452	73.9	72.3	72.6	41	46	5.8
6:05 P	4	483	73.5	72.0	72.4	41	47	5.8
6:09 P	3	583	69.4	71.8	72.3	43	47	6.3
1896. April 23.		meters.	° F.	° F.	° F.	p. ct.	p. ct.	m. p. s.
4:17 P	3	362	56.8	62.0	63.6	32	26	9.4
4:28 P	8	371	55.9	61.9	63.5	33	26	7.2
April 24.								
2:53 P	8	380	44.1	49.4	50.3	40	34	8.5
3:07 P	6	456	42.0	49.1	49.8	40	34	8.0
3:23 P	10	608	40.2	48.4	50.0	39	34	9.8
3:34 P	3	608	41.1	48.6	50.8	39	34	8.9
3:50 P	10	677	41.3	48.5	50.7	39	34	8.0
3:58 P	3	755	40.6	48.3	50.6	41	34	8.9
4:15 P	15	802	39.7	48.0	50.6	43	34	9.4
4:27 P	8	856	38.4	47.2	50.2	44	34	9.8
4:35 P	3	887	38.0	47.0	49.8	44	34	9.8
4:37 P	2	892	38.4	46.9	49.8	44	34	9.8
4:42 P	4	854	38.6	46.8	49.8	44	34	9.4
4:55 P	5	648	40.4	46.3	49.3	42	38	8.5
5:05 P	3	501	40.4	46.2	49.1	39	40	8.9
5:16 P	3	345	42.0	45.9	48.6	42	43	8.9
5:26 P	4	210	43.8	45.5	48.3	44	44	8.5
April 27.								
5:18 P	3	203	49.7	49.5	51.7	62	59	5.8
5:27 P	8	210	48.4	48.7	51.7	64	60	5.8
5:40 P	6	250	47.3	48.0	51.5	67	62	6.3
5.50 P	4	266	47.7	47.6	51.3	68	64	6.3
6:04 P	5	304	48.2	46.5	50.5	63	66	6.3
6:06 P	2	346	48.2	46.4	50.3	64	66	6.3
6:12 P	. .	272	46.1	46.1	49.7	67	68	6.3
6:14 P	. .	266	45.5	46.1	49.2	68	69	6.3
6:20 P	3	200	45.5	45.5	48.9	71	71	6.3
May 4.								
2:00 P	. .	281	72.8	74.0	76.1	46	42	7.2
2:18 P	1	533	67.0	74.7	76.3	50	. .	7.2
2:25 P	4	455	68.8	74.5	76.2	51	. .	8.9
2:40 P	1	616	65.7	73.7	76.8	55	. .	6.7
3:20 P	6	480	69.7	74.5	78.0	45	. .	5.8
3:55 P	3	533	69.2	76.2	78.2	45	. .	6.3
4:36 P	6	780	64.7	76.6	78.5	48	. .	8.0
4:50 P	6	827	62.5	76.2	78.5	50	. .	8.0
5:12 P	4	1208	57.5	75.8	77.9	55	41	8.0
May 7.								
2:53 P	5	383	37.7	44.8	48.6	61	54	8.5
3:04 P	7	558	35.7	44.6	48.1	46	55	11.2

Date and Hour.	Interval in Minutes.	Altitude above Valley.	Air Temperature at Kite.	Air Temperature on Hill.	Air Temperature in Valley.	Humidity at Kite.	Humidity on Hill.	Wind Velocity on Hill.
1896. May 7.		meters.	°F.	°F.	°F.	p. ct.	p. ct.	m. p. s.
3:15 P	5	755	35.2	44.3	47.4	36	56	10.7
3:24 P	3	797	33.9	43.9	46.9	34	56	11.2
3:42 P	10	781	34.8	43.8	46.3	31	58	8.9
3:49 P	3	1075	35.2	43.6	46.3	29	59	8.9
3:54 P	3	981	35.0	43.5	46.3	29	59	9.4
4:15 P	13	1026	36.6	43.3	46.3	25	60	9.8
4:31 P	3	992	35.9	43.3	46.2	25	63	8.5
4:39 P	3	988	35.7	43.2	46.3	27	62	6.7
4:45 P	4	901	35.5	43.2	46.5	28	62	6.3
4:57 P	7	814	36.9	42.9	46.8	32	61	7.2
5:08 P	5	736	37.3	42.9	46.5	33	61	7.6
5:17 P	4	568	39.5	42.9	46.1	32	61	7.2
5:29 P	4	393	39.0	42.8	46.2	48	60	7.2
May 8.								
3:03 P	7	331	61.6	67.7	69.2	42	41	8.5
3:13 P	3	472	59.3	66.3	69.0	44	41	8.9
4:20 P	6	866	. .	. .	. .	. .	. .	9.8
May 9.								
2:05 P	7	230	74.5	76.4	81.7	55	59	8.0
2:10 P	4	327	71.9	76.1	81.6	58	59	8.0
2:20 P	4	428	71.2	75.5	80.4	60	60	8.5
2:35 P	5	482	72.5	74.7	79.4	62	60	7.6
2:36 P	1	524	72.3	74.7	79.4	62	60	7.6
2:37 P	1	673	. .	. .	. .	. .	. .	8.0
2:43 P	3	754	69.6	74.4	78.4	64	60	7.6
2:51 P	3	921	67.6	73.8	77.6	65	61	8.5
3:04 P	3	1033	67.8	73.0	77.2	58	59	7.2
3:12 P	2	1145	68.7	74.8	77.3	53	59	7.2
3:38 P	19	1332	69.6	71.9	76.1	40	61	7.6
3:58 P	4	1126	71.2	71.8	75.5	43	61	9.4
4:15 P	4	962	72.7	70.0	75.2	51	62	8.0
4:32 P	3	782	74.8	71.1	75.2	53	62	7.6
4:43 P	3	313	78.1	70.0	73.6	56	63	8.0
4:49 P	1	250	70.3	70.8	73.1	62	63	7.2
May 14.								
4:35 P	4	388	65.8	69.6	71.8	62	61	10.3
4:58 P	20	559	63.7	69.3	71.3	66	64	10.7
5.14 P	10	553	63.7	67.9	70.8	67	70	10.7
5:27 P	4	383	62.0	66.5	69.8	87	73	11.6
June 2.								
4:00 P	6	360	60.1	64.1	67.8	51	49	10.3
4:20 P	13	560	57.8	64.3	68.3	53	50	11.2
4:30 P	8	608	55.5	64.2	68.8	55	48	12.1
4:48 P	3	872	51.8	65.3	67.8	58	49	10.7
4:58 P	4	892	51.3	64.3	67.7	59	49	11.2
5:27 P	6	1084	48.1	64.0	68.0	63	49	10.7

Date and Hour.	Interval in Minutes.	Altitude above Valley.	Air Temperature at Kite.	Air Temperature on Hill.	Air Temperature in Valley.	Humidity at Kite.	Humidity on Hill.	Wind Velocity on Hill.
1896. June 2.		meters.	°F.	°F.	°F.	p. ct.	p. ct.	m. p. s.
5.55 P	15	878	50.4	63.3	67.2	61	51	9.4
6:12 P	3	665	53.8	62.7	66.4	57	51	8.9
6:23 P	3	480	56.8	62.2	65.8	56	52	7.6
6:41 P	2	206	60.6	60.8	64.3	55	54	7.6
June 6.								
10:05 A	10	446	52.9	60.3	61.4	83	79	10.3
10:20 A	12	560	57.4	60.0	61.2	60	76	9.4
10:35 A	9	640	57.4	60.3	61.5	61	77	7.2
10:45 A	3	842	57.9	60.4	61.7	62	77	7.6
0:12 P	43	700	56.0	60.7	62.0	70	79	8.0
0:18 P	6	769	55.6	60.8	61.8	70	79	6.7
0:35 P	11	776	56.9	60.4	62.0	69	78	6.7
0:40 P	4	726	57.0	60.4	62.2	69	78	8.5
1:04 P	8	806	56.5	61.3	63.2	70	71	6.7
1:56 P	4	1013	55.1	59.9	60.1	70	84	8.5
2:49 P	6	981	55.6	57.8	59.5	76	86	8.9
3:11 P	7	874	56.9	57.7	59.2	74	86	8.5
4:00 P	. .	1006	55.6	56.1	57.5	75	94	6.7
4:42 P	. .	470	53.2	56.9	57.8	88	90	5.4
4:46 P	. .	470	54.7	56.1	57.8	83	90	4.9
4:48 P	. .	441	55.4	57.2	57.8	86	91	4.9
4:49 P	. .	406	54.0	57.2	57.8	89	91	4.9
4:53 P	. .	402	52.9	57.3	58.0	91	91	4.9
4:55 P	. .	362	53.6	57.1	58.0	92	92	4.9
4:56 P	. .	296	54.5	57.1	58.0	92	92	4.9
June 11.								
4:56 P	5	190	64.0	66.6	69.5	48	50	8.0
5:07 P	8	270	63.8	66.6	68.9	46	48	8.5
5:21 P	5	534	59.1	65.9	68.9	45	46	12.1
5:30 P	4	631	57.6	65.7	68.4	46	45	11.6
5:35 P	2	735	56.3	65.6	68.1	47	45	12.1
5:38 P	3	747	55.6	65.5	67.8	46	45	9.4
6:19 P	3	273	63.1	64.4	67.6	44	48	8.9
June 12.								
5:08 P	3	331	60.7	63.3	68.0	53	53	5.4
5:11 P	2	268	61.6	63.3	68.0	. .	53	4.9
June 13.								
5:18 P	2	320	57.3	58.5	62.0	68	60	6.3
5:45 P	4	366	58.8	57.9	61.0	75	61	6.3
5:51 P	6	456	58.8	57.8	60.5	76	61	5.4
5:53 P	. .	441	58.4	57.8	60.4	76	61	5.4
6:00 P	3	443	57.1	57.7	59.9	83	61	6.3
6:12 P	3	356	56.1	57.4	59.5	80	62	6.3
6:22 P	4	212	56.1	56.9	59.3	. .	. .	6.7
June 17.								
2:32 P	4	496	62.1	67.6	72.9	. .	57	10.3

Date and Hour.	Interval in Minutes.	Altitude above Valley.	Air Temperature at Kite.	Air Temperature on Hill.	Air Temperature in Valley.	Humidity at Kite.	Humidity on Hill.	Wind Velocity on Hill.
1896. June 29.		meters.	°F.	°F.	°F.	p. ct.	p. ct.	m. p. s.
2:29 P	11	381	71.6	76.8	79.0	50	48	8.9
2:37 P	2	604	68.4	76.6	77.3	51	47	9.8
2:48 P	4	772	65.3	75.7	76.7	57	49	8.9
3:03 P	6	1037	60.8	75.0	77.0	63	49	9.8
3:18 P	9	1250	57.9	75.4	78.3	70	50	10.3
3:21 P	3	1233	58.1	75.7	78.3	70	49	12.1
3:36 P	. .	1337	56.8	75.7	79.1	73	49	9.4
4:00 P	5	260	74.8	76.0	79.0	48	48	9.4
July 3.								
3:46 P	7	336	56.5	59.2	62.1	. .	87	8.0
3:50 P	. .	423	54.7	59.2	62.0	. .	88	8.5
3:57 P	6	450	55.1	58.9	62.0	. .	89	8.5
July 10.								
2:44 P	6	375	80.1	84.8	87.2	47	46	10.3
2:56 P	7	520	77.9	84.6	87.1	49	46	8.5
3:20 P	. .	975	69.5	84.4	86.8	65	47	8.5
3:31 P	5	894	71.3	84.3	86.7	59	47	8.5
3:42 P	3	910	71.5	84.2	86.5	60	48	8.0
3:57 P	2	785	72.8	84.1	86.4	61	49	8.0
4:10 P	. .	596	76.6	83.8	86.3	57	49	7.6
4:23 P	4	337	80.4	83.2	85.3	54	50	6.7
July 20.								
9:30 A	6	401	66.8	72.6	76.2	80	72	8.5
9:40 A	4	634	63.2	73.2	77.4	88	72	6.3
10:38 A	10	811	60.5	74.1	78.5	94	73	6.3
10:47 A	5	994	58.9	73.8	78.4	100	73	7.2
10:54 A	4	1047	58.7	73.8	78.8	100	72	7.6
11:04 A	3	1368	59.2	73.8	79.1	. .	71	8.5
11:14 A	2	1700	57.4	73.5	78.0	Very	73	7.6
11:29 A	4	1795	59.2	72.1	77.6	dry	76	8.9
0:19 P	6	1950	57.3	72.1	76.4	. .	76	9.8
1:10 P	3	1290	58.0	72.5	77.4	100	75	8.9
1:26 P	4	1095	59.6	73.8	76.4	96	63	9.8
1:34 P	. .	1131	58.7	73.6	77.9	. .	. .	10.3
2:09 P	10	837	61.8	74.1	78.2	. .	68	10.3
2:23 P	4	666	64.5	74.1	77.0	. .	68	10.3
2:38 P	5	484	66.1	72.5	76.1	. .	70	9.4
2:51 P	3	354	68.1	71.8	75.4	. .	75	10.3
July 22.								
11:52 A	4	380	. . .	. .	. .	85	82	5.8
0:02 P	6	544	70.5	75.3	80.6	78	82	6.3
0:16 P	3	716	69.5	75.4	81.0	. .	81	6.3
0:28 P	3	880	67.0	76.4	82.0	. .	80	5.8
0:42 P	4	1271	64.8	75.7	81.8	. .	79	6.7
0:56 P	3	1418	63.3	77.4	81.9	. .	78	5.4
1:13 P	5	1540	64.1	76.9	82.0	. .	74	5.8

Date and Hour.	Interval in Minutes.	Altitude above Valley.	Air Temperature at Kite.	Air Temperature on Hill.	Air Temperature in Valley.	Humidity at Kite.	Humidity on Hill.	Wind Velocity on Hill.
1896. July 22.		meters.	°F.	°F.	°F.	p. ct.	p. ct.	m. p. s.
1:38 P	5	1677	61.6	79.8	82.2	. .	72	4.5
1:45 P	3	1500	63.6	78.9	82.3	. .	70	4.5
2:24 P	2	1366	65.2	77.4	83.2	. .	78	8.0
2:35 P	14	1398	65.5	76.2	82.0	. .	80	8.9
3:55 P	. .	1304	65.8	74.9	80.8	. .	83	7.6
4:08 P	. .	1247	66.1	75.0	80.8	. .	82	8.0
4:29 P	6	1160	64.0	73.2	80.5	. .	85	8.9
4:46 P	3	810	64.6	73.7	79.5	. .	85	6.3
4:58 P	2	842	67.5	73.9	79.8	. .	86	6.3
5:14 P	3	590	67.6	72.9	79.0	. .	89	4.9
5:18 P	. .	490	68.2	72.9	78.6	. .	89	5.4
5:24 P	3	376	68.7	72.9	77.8	. .	. .	6.3
July 23.								
1:24 P	3	212	74.0	76.9	79.8	49	52	11.6
1:33 P	2	390	71.3	77.2	79.6	51	52	10.3
1:43 P	4	548	70.0	77.0	80.0	52	50	11.6
1:58 P	5	858	65.5	76.7	80.0	57	49	12.1
2:09 P	6	874	64.3	. .	79.9	58	47	11.6
2:45 P	. .	482	69.4	. .	79.4	49	49	9.8
3:36 P	3	478	69.2	. .	78.2	45	44	11.2
3:45 P	3	864	63.6	. .	78.3	52	45	9.4
3:53 P	. .	1065	60.6	. .	78.3	56	46	10.7
3:56 P	2	1025	61.1	. .	78.1	55	46	10.7
4:13 P	4	1206	58.6	. .	77.8	62	46	10.3
4:25 P	5	1323	55.8	. .	78.0	68	46	10.3
4:37 P	3	1451	53.2	. .	78.0	. .	46	10.3
4:44 P	5	1607	51.4	. .	77.9	77	47	9.8
4:59 P	2	1654	50.9	. .	77.0	81	47	10.3
5:31 P	3	1384	53.7	. .	77.3	74	47	8.5
6:08 P	15	863	62.7	. .	74.3	57	49	8.0
6:15 P	5	510	67.7	. .	74.2	49	50	7.6
Aug. 1.								
2:51 P	2	673	. . .	. .	. .	47	36	6.7
3:05 P	4	1250	. . .	72.4	75.4	58	40	7.2
3:23 P	4	1209	. . .	. .	. .	64	43	8.5
3:59 P	10	1586	46.9	71.4	75.5	69	45	8.5
4:12 P	5	1700	45.0	69.3	75.0	70	48	8.5
4:18 P	4	1816	46.2	69.0	74.8	71	50	8.5
4:25 P	4	1853	48.4	68.9	74.7	. .	50	8.5
4:29 P	3	1883	49.3	68.7	74.3	. .	50	8.5
4:34 P	5	1942	48.6	68.5	74.5	. .	50	8.0
4:42 P	4	2164	48.2	68.2	74.4	. .	50	9.4
4:46 P	3	2095	48.0	67.9	74.3	. .	51	8.9
4:52 P	3	2200	49.6	67.9	74.2	. .	51	8.9
4:54 P	. .	2177	49.5	68.0	74.0	. .	51	8.9
4:58 P	. .	2112	49.1	69.1	74.0	20?	51	8.0

Date and Hour.	Interval in Minutes.	Altitude above Valley.	Air Temperature at Kite.	Air Temperature on Hill.	Air Temperature in Valley.	Humidity at Kite.	Humidity on Hill.	Wind Velocity on Hill.
1896. Aug. 1.		meters.	° F.	° F.	° F.	p. ct.	p. ct.	m. p. s.
5:20 P	3	1596	46.2	67.6	73.6	40	53	8.0
5:38 P	3	1290	50.4	69.3	72.2	75	48	9.8
5:53 P	3	1198	52.7	68.9	71.0	. .	47	8.5
6:09 P	3	849	57.2	68.1	69.2	. .	48	8.5
6:28 P	3	518	62.1	66.7	67.2	. .	48	9.4
Aug. 17.								
10:41 A	1	347	69.6	73.2	75.3	71	61	7.2
11:00 A	1	556	66.0	73.1	75.4	78	66	5.8
11:50 A	1	902	60.7	73.9	77.2	. .	57	8.5
11:55 A	1	767	63.5	73.9	76.7	. .	57	7.6
0:06 P	1	940	61.3	74.1	77.2	. .	54	7.2
0:23 P	1	320	70.7	74.3	77.1	. .	51	7.2
0:57 P	1	980	59.9	74.0	. .	. .	48	7.2
1:25 P	3	426	70.7	75.1	76.5	. .	45	6.7
1:28 P	1	626	67.8	75.1	75.3	. .	44	6.3
1:30 P	1	604	68.0	73.9	75.2	. .	45	5.8
Aug. 22.								
2:08 P	14	461	64.3	68.7	72.6	82	71	8.0
2:23 P	6	666	60.1	69.0	72.5	94	71	8.0
2:38 P	4	880	57.3	68.9	72.4	100	70	7.2
2:58 P	6	933	56.0	68.8	72.4	100	70	5.4
3:28 P	4	1014	55.2	67.7	70.6	99	68	8.5
3:43 P	3	1156	52.9	67.8	70.5	100	69	5.8
4:10 P	4	1232	52.1	68.8	70.3	100	69	6.3
4:12 P	. .	1265	51.9	66.9	70.3	100	69	5.4
4:27 P	. .	1176	52.2	66.9	71.2	100	71	5.4
4:41 P	7	1259	51.6	68.7	70.8	93	70	6.3
4:50 P	. .	1318	51.8	67.6	71.4	87	71	7.2
5:12 P	3	1168	54.8	66.6	70.3	89	74	8.0
5:31 P	. .	1003	55.3	65.9	70.0	77	77	6.7
5:48 P	4	752	59.5	65.8	69.1	75	80	8.0
6:02 P	. .	472	. .	. .	. .	90	81	7.6
Aug. 26.								
4:13 P	3	511	67.9	73.2	78.0	52	46	7.6
4:28 P	5	800	62.8	72.6	77.7	60	45	8.5
4:48 P	4	1041	58.0	72.0	77.2	74	48	6.3
5:15 P	3	1315	53.6	70.4	75.6	82	51	6.3
5:27 P	7	1403	52.6	70.0	74.0	62	52	5.8
5:46 P	3	1562	49.9	68.1	71.0	59	63	5.8
6:01 P	. .	1693	48.1	66.8	68.9	59	67	6.7
6:22 P	3	1667	48.2	65.9	67.2	59	70	7.6
6:29 P	. .	1692	48.1	65.6	66.9	57	70	7.2
6:42 P	. .	1667	48.2	64.9	66.0	54	70	7.2
7:00 P	. .	1665	48.1	63.8	65.4	46	73	8.5
8:10 P	. .	1525	51.9	62.0	64.2	46	73	8.5
8:58 P	7	1328	55.3	61.2	61.6	43	77	8.0

Date and Hour.	Interval in Minutes.	Altitude above Valley.	Air Temperature at Kite.	Air Temperature on Hill.	Air Temperature in Valley.	Humidity at Kite.	Humidity on Hill.	Wind Velocity on Hill.
1896. Aug. 26.		meters.	° F.	° F.	° F.	p. ct.	p. ct.	m. s. p.
9:13 P	5	1142	57.0	61.0	60.5	37	79	7.6
9:28 P	6	925	56.9	60.9	59.3	70	81	6.7
9:42 P	6	560	60.8	60.1	58.2	86	86	6.7
Aug. 31.								
10:16 A	3	496	62.6	72.2	75.4	78	60	8.5
10:34 A	3	915	57.6	74.2	76.2	84	58	6.7
10:41 A	3	1183	. .	74.4	76.4	. .	58	8.0
10:54 A	. .	1273	. .	75.1	76.9	100	57	7.6
11:00 A	. .	1410	. .	. .	. .	100	. .	. .
11:12 A	. .	1542	55.4	75.9	77.4	54	56	6.7
11:23 A	2	1470	55.6	76.5	77.4	53	56	7.6
11:34 A	4	1771	51.5	76.0	77.9	. .	55	8.5
11:38 A	4	1816	50.2	77.3	78.0	. .	55	7.6
11:59 A	5	2123	46.8	75.6	76.2	70	56	8.6
Sept. 8.								
4:12 P	. .	280	58.4	58.7	62.2	55	65	8.0
4:34 P	4	470	55.6	58.1	61.4	55	69	6.7
4:47 P	3	801	57.0	57.9	60.8	33	69	7.2
5:05 P	9	1244	55.9	57.3	60.3	28	74	6.3
5:26 P	3	1372	55.4	56.9	59.3	29	78	7.2
5:29 P	. .	1360	55.4	56.7	59.3	29	79	6.7
5:42 P	3	1255	56.4	56.4	58.8	29	82	6.7
5:54 P	4	1098	57.7	56.1	58.3	27	84	7.2
6:07 P	3	790	55.6	56.0	58.3	42	83	7.6
6:22 P	2	482	57.2	56.1	57.6	53	83	7.6
Sept. 11.								
4:54 P	3	475	77.4	79.1	82.9	70	75	5.4
5:08 P	3	612	75.9	78.0	81.2	71	76	5.4
5:15 P	3	617	75.9	77.7	80.8	71	76	5.8
5:31 P	4	471	77.4	76.1	78.8	70	78	6.3
Sept. 16.								
9:46 A	4	438	53.1	59.9	63.8	99	75	7.6
10:02 A	3	590	51.4	59.3	63.7	100	75	8.0
10:28 A	4	511	51.0	59.1	63.7	100	76	7.2
11:00 A	5	576	52.0	60.3	64.3	100	76	7.2
11:19 A	4	601	51.7	60.0	64.1	99	75	7.6
11:36 A	2	390	54.2	60.0	64.5	85	75	7.6
11:50 A	7	394	54.9	59.1	64.4	87	77	6.7
11:55 A	4	392	54.2	59.1	64.4	90	77	6.3
1:01 P	4	522	55.3	59.1	64.9	73	80	6.3
1:23 P	3	478	53.4	58.9	63.4	98	81	7.2
1:38 P	3	281	55.7	59.3	63.2	90	81	6.7
4:07 P	4	516	56.2	56.5	59.7	. .	88	7.2
4:09 P	2	520	56.1	56.2	59.8	70	88	. .
Sept. 17.								
2:32 P	4	478	59.0	64.4	69.3	85	78	8.0
2:36 P	3	399	59.7	64.3	69.2	83	78	7.2

Date and Hour.	Interval in Minutes.	Altitude above Valley.	Air Temperature at Kite.	Air Temperature on Hill.	Air Temperature in Valley.	Humidity at Kite.	Humidity on Hill.	Wind Velocity on Hill.
1896. Sept. 17.		meters.	° F.	° F.	° F.	p. ct.	p. ct.	m. p. s.
2:55 P	3	839	53.5	63.4	68.0	100.	84	6.3
3:08 P	7	1036	55.0	63.3	68.0	80	85	7.6
4:17 P	3	504	57.3	63.2	66.4	. .	84	7.6
4:20 P	3	507	57.3	63.3	66.4	. .	84	8.5
Sept. 18.								
10:03 A	4	433	57.1	62.8	66.7	56	53	12.1
10:18 A	3	652	54.6	63.1	67.2	61	53	10.3
10:32 A	. .	747	52.7	64.0	67.3	65	54	9.4
10:48 A	. .	1024	49.8	65.2	67.6	74	52	8.5
11:07 A	5	890	53.2	65.9	68.8	64	50	8.9
11:20 A	3	812	54.0	66.0	69.0	62	51	7.6
11:32 A	2	601	57.8	66.3	69.3	58	50	8.9
11:44 A	2	416	61.2	66.2	69.0	49	48	10.3
Sept. 19.								
3:49 P	4	372	67.8	73.4	77.8	98	87	10.7
3:53 P	4	425	66.9	72.4	77.8	100	90	11.2
4:00 P	. .	414	69.9	72.2	77.4	84	89	11.6
Sept. 20.								
3:39 P	2	463	55.2	61.7	64.2	. .	47	. .
3:46 P	2	768	49.8	61.7	64.2	. .	47	. .
5:44 P	3	2230	. .	. .	. .	. .	54	. .
10:05 P	5	504	49.7	49.3	45.5	. .	84	. .
Sept. 24.								
2:12 P	1	393	54.6	58.6	63.3	59	57	9.4
2:14 P	1	245	56.8	59.6	63.2	59	57	9.4
2:19 P	1	376	55.4	60.5	63.0	59	56	7.6
2:41 P	3	301	55.9	58.5	62.9	61	61	6.3
3:33 P	1	365	55.3	56.7	60.8	61	64	9.8
4:01 P	1	734	50.2	57.8	60.8	70	65	7.2
Sept. 25.								
3:01 P	. .	537	53.7	61.2	67.9	70	60	9.4
3:26 P	20	517	52.9	61.4	66.5	71	60	8.5
3:38 P	12	522	53.4	61.0	66.0	70	60	10.3
3:50 P	. .	830	49.4	59.9	65.1	76	60	9.4
3:55 P	5	874	49.2	59.8	65.0	76	60	9.4
4:08 P	. .	526	53.6	59.0	64.0	69	61	10.3
5:32 P	2	730	48.2	54.3	57.2	100	76	9.4
5:47 P	3	623	50.1	54.0	56.0	76	77	8.9
5:56 P	2	500	51.7	53.4	55.3	86	76	8.9
Sept. 29.								
3:27 P	. .	286	59.3	61.6	64.1	73	71	6.7
3:35 P	2	323	58.9	61.3	63.4	76	74	7.2
3:44 P	3	308	58.0	60.6	63.2	83	78	5.8
3:54 P	. .	455	55.7	60.4	62.5	88	80	6.7
4:12 P	3	685	51.5	59.5	61.5	92	82	7.2
4:27 P	3	796	49.0	58.7	61.0	99	85	7.6

Date and Hour.	Interval in Minutes.	Altitude above Valley.	Air Temperature at Kite.	Air Temperature on Hill.	Air Temperature in Valley.	Humidity at Kite.	Humidity on Hill.	Wind Velocity on Hill.
1896. Sept. 29.		meters.	° F.	° F.	° F.	p. ct.	p. ct.	m. p. s.
4:37 P	. .	768	50.4	58.6	60.9	91	86	8.5
4:43 P	. .	917	53.7	58.3	60.8	100	86	8.5
4:49 P	4	1054	52.6	58.0	60.8	100	86	8.5
5:06 P	. .	1334	50.3	57.2	60.0	100	87	8.0
5:18 P	4	1450	49.0	56.7	59.8	100	88	8.5
5:22 P	. .	1460	48.5	56.7	59.8	100	89	8.0
5:36 P	. .	1586	46.5	56.6	59.2	99	90	7.6
Oct. 6.								
11:08 A	2	278	44.0	45.5	49.4	93	85	6.7
11:21 A	3	502	41.4	46.0	49.5	99	83	7.2
11:29 A	4	630	39.7	46.1	49.5	100	81	7.2
11:45 A	. .	499	39.6	45.3	48.4	100	88	8.0
11:54 A	. .	493	40.0	44.9	48.4	100	89	8.0
0:15 P	5	798	36.4	45.1	48.7	100	89	7.2
0:17 P	2	776	36.7	45.1	48.7	99	84	7.2
0:28 P	. .	860	36.2	45.8	49.3	100	85	6.7
0:42 P	. .	577	39.6	46.1	49.8	99	84	6.3
0:45 P	3	498	41.7	46.1	49.8	98	84	6.3
Oct. 8.								
10:16 A	2	611	38.8	47.9	48.9	72	58	9.8
10:43 A	3	798	36.6	46.7	48.9	78	59	8.5
11:00 A	4	826	. .	47.7	49.1	79	58	7.6
11:05 A	2	938	32.4	47.6	49.1	96	58	8.5
11:20 A	1	776	37.4	47.1	49.2	82	59	8.0
11:39 A	3	528	41.4	46.9	50.0	72	59	8.9
0:31 P	4	551	41.2	47.4	50.2	70	59	8.9
0:55 P	3	957	34.7	47.9	50.4	90	57	8.5
0:59 P	2	1098	32.2	47.9	51.3	92	57	8.5
1:18 P	. .	907	36.7	48.3	51.4	76	55	9.4
1:35 P	4	1370	30.6	49.4	52.3	92	54	8.9
1:45 P	4	1355	29.4	48.8	52.6	97	53	9.8
1:47 P	. .	1396	28.7	48.8	52.5	98	54	9.8
1:58 P	. .	1358	28.3	49.0	51.6	100	54	10.3
2:20 P	5	1599	25.5	48.7	51.9	98	54	9.4
2:59 P	2	1446	27.2	48.0	51.4	97	55	10.3
3:28 P	. .	1920	27.1	47.8	50.3	66	57	10.3
3:34 P	. .	1588	25.1	47.4	50.2	91	57	8.9
4:20 P	2	2470	23.7	46.6	49.3	55	59	8.0
4:41 P	. .	2828	20.4	45.8	48.7	53	61	8.0
5:12 P	. .	2489	23.6	45.3	47.8	50	64	8.0
5:48 P	. .	1940	27.9	44.6	46.6	59	67	6.3
6:18 P	. .	1625	23.6	43.6	44.8	100	70	7.2
6:36 P	. .	1495	25.0	43.5	43.6	100	71	8.5
7:17 P	. .	1405	26.3	42.3	40.0	88	74	8.0
7:35 P	. .	1425	26.3	41.6	38.4	87	76	8.0
8:10 P	. .	1395	26.3	41.1	37.1	79	76	6.7

Date and Hour.	Interval in Minutes.	Altitude above Valley.	Air Temperature			Humidity		Wind Velocity on Hill.
			at Kite.	on Hill.	in Valley.	at Kite.	on Hill.	
1896. Oct. 8.		meters.	°F.	°F.	°F.	p. ct.	p. ct.	m. p. s.
8:24 P	. .	1160	30.3	41.3	37.0	70	77	6.7
8:50 P	. .	650	37.2	40.5	35.9	62	77	6.7
9:03 P	. .	240	41.7	39.9	35.3	58	79	6.7
Oct. 31.								
2:42 P	6	432	66.9	72.1	73.9	47	43	8.0
2:47 P	4	498	65.6	72.0	74.0	49	44	6.7
3:58 P	. .	418	66.1	69.0	71.4	49	47	7.2
4:09 P	3	620	62.5	68.3	70.5	57	48	6.3
4:24 P	3	785	60.2	67.7	69.7	59	49	6.3
4:37 P	4	983	55.7	66.7	68.3	65	50	6.3
4:41 P	. .	1112	54.6	66.5	67.9	65	51	6.3
Nov. 17.								
2:17 P	. .	250	66.7	68.2	71.3	56	54	8.9
2:42 P	8	473	63.2	67.9	70.8	62	54	8.5
2:53 P	5	760	58.0	67.9	70.5	71	54	10.3
3:02 P	3	1004	53.3	67.6	70.4	79	55	10.3
3:14 P	6	1255	49.2	67.4	70.0	92	56	9.8
3:28 P	. .	1492	. .	. .	. .	98	56	7.6
3:31 P	. .	1572	43.8	67.1	69.5	100	57	8.9
3:39 P	3	1282	. .	. .	. .	81	57	8.5
4:11 P	2	1201	51.0	66.1	67.9	. .	57	7.6
4:32 P	4	1065	51.7	65.8	66.9	. .	58	8.9
5:04 P	5	467	61.3	64.7	65.1	. .	61	6.7
Nov. 18.								
0:14 P	3	364	41.6	44.5	48.1	98	86	4.5
0:31 P	2	513	39.3	44.6	48.0	100	86	4.5
0:35 P	. .	502	39.4	44.7	48.0	100	86	4.5
0:47 P	2	507	39.8	45.1	48.2	100	85	4.5
1:35 P	3	461	40.7	44.9	48.0	. .	86	4.5
1:50 P	6	312	42.7	44.9	48.0	98	87	4.5
Nov. 30.								
9:58 A	. .	373	26.3	27.0	30.8	78	100	6.7
10:05 A	3	488	26.7	27.1	30.9	73	100	6.3
10:09 A	. .	505	26.7	27.2	31.0	72	100	6.3
10:26 A	4	491	26.9	27.4	31.1	70	100	6.3
10:41 A	4	626	25.6	27.5	31.2	74	100	6.3
0:04 P	3	563	25.8	28.2	31.8	74	88	6.3
0:48 P	6	479	26.7	28.3	32.0	72	82	5.8
1:00 P	4	469	26.9	28.4	32.0	71	84	4.5
1:05 P	3	548	25.8	28.5	32.0	72	83	4.9
1:38 P	12	535	25.6	28.8	31.9	72	81	4.5
1:45 P	. .	578	25.4	28.8	31.9	74	81	5.8
1.50 P	. .	611	25.2	28.9	31.9	75	81	6.3
2:04 P	3	443	26.9	28.9	31.9	70	83	5.4
2:14 P	3	349	26.7	28.9	31.9	77	83	5.4
2:19 P	. .	289	26.9	28.9	31.9	83	84	5.4

Date and Hour.	Interval in Minutes.	Altitude above Valley.	Air Temperature			Humidity		Wind Velocity on Hill.
			at Kite	on Hill.	in Valley.	at Kite.	on Hill.	
1896. Dec. 12.		meters.	°F.	°F.	°F.	p. ct.	p. ct.	m. p. s.
10:15 A	10	467	31.7	36.9	39.1	87	76	8.9
10:40 A	11	240	36.7	37.4	40.4	83	76	10.3
2:15 P	1	300	40.3	44.2	46.4	68	63	7.6
2:28 P	1	410	38.5	44.2	45.7	70	63	. .
2:33 P	1	670	36.7	44.3	45.7	64	63	6.3
2:45 P	4	741	42.3	44.4	45.7	50	63	6.3
2:50 P	3	766	40.3	44.5	45.6	54	63	6.7
2:57 P	. .	753	37.8	44.5	45.6	60	63	6.3
3:03 P	. .	780	44.8	44.5	45.3	42	62	6.3
3:13 P	. .	660	37.2	44.5	44.9	62	63	5.8
3:22 P	. .	457	39.8	44.4	44.3	68	63	5.8
Dec. 15.								
2:10 P	3	319	22.7	26.6	30.0	82	75	11.2
2:19 P	2	444	18.8	26.5	29.9	85	75	10.7
2:27 P	2	765	15.5	26.5	29.9	100	76	10.7
2:36 P	. .	608	16.5	26.6	29.8	100	76	10.7
2:42 P	. .	571	18.4	26.4	29.5	100	76	10.7
2:55 P	2	370	22.9	26.2	29.4	. .	76	12.1
1897. Jan. 2.								
0:01 P	4	524	30.1	36.9	39.6	100	81	7.6
0:07 P	. .	666	28.5	36.9	39.7	100	81	7.6
0:14 P	6	760	47.9	37.0	39.7	62	81	7.6
0:32 P	7	810	50.9	37.3	39.9	53	82	9.4
0.35 P	3	715	49.8	37.4	39.9	58	82	8.5
0:40 P	5	790	51.3	37.6	39.9	52	82	7.6
0:58 P	. .	832	52.7	37.7	40.0	51	82	8.9
1:02 P	. .	818	52.5	37.8	40.3	52	82	7.2
1:13 P	. .	806	52.2	37.9	40.5	. .	81	7.2
1:20 P	. .	772	51.2	38.3	40.7	53	80	7.2
1:32 P	. .	848	52.9	38.6	41.8	55	80	8.5
2:01 P	. .	772	54.1	39.5	42.3	50	78	8.5
2:10 P	. .	755	54.0	39.8	42.5	51	77	7.6
2:38 P	. .	890	55.1	39.8	42.0	48	80	7.6
2:42 P	. .	872	55.3	39.8	41.5	. .	80	. .
2:44 P	. .	973	54.9	39.6	41.2	50	80	. .
2:55 P	. .	994	54.7	39.5	41.0	50	80	8.0
3:03 P	. .	949	55.0	39.4	40.5	51	81	. .
3:12 P	. .	973	54.9	39.0	40.2	52	82	9.8
3:16 P	. .	1047	53.9	39.0	40.0	54	82	. .
3:29 P	. .	1076	53.6	38.5	39.9	53	83	7.6
3:36 P	. .	1088	53.4	38.4	39.8	53	83	. .
3:52 P	. .	1096	53.5	37.9	39.1	52	84	8.0
3:57 P	. .	1092	53.7	37.9	39.0	51	85	8.0
4:27 P	. .	1031	54.8	37.0	37.4	51	88	8.0
4:44 P	. .	937	55.6	36.8	36.9	49	89	8.5

Date and Hour.	Interval in Minutes.	Altitude above Valley.	Air Temperature at Kite.	Air Temperature on Hill.	Air Temperature in Valley.	Humidity at Kite.	Humidity on Hill.	Wind Velocity on Hill.
1897. Jan. 2.		*meters.*	° F.	° F.	° F.	*p. ct.*	*p. ct.*	*m. p. s.*
4:59 P	. .	873	55.9	36.7	36.6	49	90	8.0
5:10 P	. .	853	56.1	36.7	36.8	48	90	8.9
5:20 P	. .	600	47.9	36.7	37.0	68	90	8.5
5:25 P	. .	583	45.8	36.7	36.9	70	90	8.5
5:32 P	. .	527	35.9	36.7	36.8	76	90	8.5
5:35 P	. .	440	34.0	36.7	36.7	98	90	8.5
5:40 P	. .	270	35.1	36.7	36.6	98	90	8.5
Jan. 19.								
11:50 A	3	481	− 4.4	2.3	7.0	29	30	10.3
11:59 A	3	663	− 7.0	2.4	7.2	30	30	11.2
0:09 P	3	900	−10.2	2.5	7.5	. .	30	11.2
0:12 P	2	1011	−12.2	2.6	7.7	. .	30	11.2
0:23 P	4	1156	−15.6	2.9	7.8	. .	30	12.1
0:26 P	. .	1234	−16.5	3.1	7.9	32	30	12.1
0:44 P	3	930	−12.5	3.6	8.2	32	30	9.8
0:47 P	2	721	− 7.1	3.6	8.6	33	30	10.3
1:01 P	4	617	− 4.5	3.9	8.8	32	29	9.8
1:11 P	2	477	− 3.9	4.2	9.5	32	29	9.8
Feb. 9.								
3:05 P	2	351	29.8	34.7	38.1	50	48	8.5
3:10 P	2	605	25.8	34.7	38.1	52	48	9.8
3:19 P	3	842	22.6	34.7	38.1	55	48	9.4
3:25 P	6	900	22.1	34.7	38.1	58	48	9.4
3:30 P	3	1018	19.5	34.6	38.1	61	48	10.3
3:40 P	3	625	26.1	34.6	37.6	57	48	8.0

Date and Hour.	Interval in Minutes.	Altitude above Valley.	Air Temperature at Kite.	Air Temperature on Hill.	Air Temperature in Valley.	Humidity at Kite.	Humidity on Hill.	Wind Velocity on Hill.
1897. Feb. 9.		*meters.*	° F.	° F.	° F.	*p. ct.*	*p. ct.*	*m. p. s.*
3:45 P	5	665	25.7	34.6	37.3	57	48	8.5
3:48 P	. .	552	28.0	34.6	37.2	53	48	8.5
Feb. 10.								
3:18 P	2	385	28.0	32.1	35.8	35	32	6.7
3:39 P	3	576	24.7	31.8	35.2	39	33	9.8
3:43 P	. .	610	24.0	31.8	35.1	40	33	10.3
3:53 P	3	760	21.6	31.3	34.6	43	32	9.4
4:08 P	4	807	21.0	30.9	34.3	43	32	8.5
4:12 P	. .	842	20.3	30.8	34.2	44	32	8.5
4:20 P	2	990	18.0	30.7	34.2	45	32	8.5
4:25 P	2	1253	15.9	30.7	34.0	45	32	10.3
4:36 P	9	1540	15.2	30.3	33.2	40	33	7.6
4:43 P	2	1354	15.1	30.2	32.6	39	33	7.6
4:51 P	3	1656	13.8	29.8	31.9	39	33	5.8
5:01 P	2	1391	15.6	29.7	31.3	39	35	7.2
5:07 P	4	1542	13.7	28.9	31.1	39	35	6.7
5:18 P	4	1864	13.1	28.7	30.7	37	36	6.3
5:26 P	2	1846	13.5	28.3	30.4	37	37	6.3
5:32 P	3	1568	15.5	28.1	30.0	38	38	6.3
5:40 P	5	1590	15.5	27.8	29.6	38	38	6.7
5:57 P	7	1425	17.0	27.1	29.2	38	39	7.6
6:03 P	2	1310	16.1	26.9	29.1	39	39	7.6
6:06 P	3	1380	16.5	26.8	28.7	39	39	7.6
6:16 P	3	990	18.0	26.7	28.7	40	40	7.6
6:30 P	2	743	19.9	26.2	28.6	42	41	7.6
6:36 P	2	640	21.4	25.9	28.1	44	42	6.7

NOTE. — The second column gives the length of the interval, ending with the time given in the first column, that the meteorograph remained near the same altitude. The third column gives the mean altitude during this interval. The fourth and seventh columns, respectively, give the temperature and relative humidity recorded by the meteorograph at the end of the interval and at the time given in the first column. The remaining columns give synchronous observations at the ground. The summit of the hill is 180 meters above the valley, which is 15 meters above sea level.

The wind velocities ordinarily recorded by anemometers are about 18 per cent higher than the true velocities. The wind velocities given in Tables XVII. and XVIII., and in the following Discussion, are corrected to true velocities.

REMARKS.

1896.

April 8. Sky clear except for a few strato-cumulus. Temperature below normal but rising. Wind ENE; kites from NE at 445 meters, and from N above 700 meters.

April 11. Sky partly covered with cirro-cumulus. Temperature above normal and rising. Wind W; kites from W at highest point.

April 13. Sky partly covered with fracto-cumulus during the second flight. Temperature very high for the season. The wind was from WSW and backed to SSW and SW at the end of the flight. The kites entered the current from the W at 528 meters, and gradually shifted around to NW when 1,300 meters was reached. Electricity strong at the highest point.

April 15. Sky clear except for a few cirrus. Temperature exceptionally high for the season. In descending, the kites shifted suddenly from a WSW to a S current at the altitude of 437 meters. Wind S; kites from SW at the highest point.

April 23. Sky clear except for a few cirro-stratus and fracto-cumulus. Temperature above normal. Winds exceptionally variable. Kites and instrument fell in trees on the hillside. Wind NW.

April 24. Sky nearly covered with a sheet of cirro-stratus. Temperature slightly below normal and falling. Wind ESE; kites from E at 608 meters, from ENE at 677 meters, and from NE at 856 meters.

April 27. Sky about one tenth covered with cirrus. Temperature slightly below normal and rising slowly. Wind ESE; kites from SE at 266 meters, and from S above 300 meters.

May 4. Sky about eight tenths covered with cumulus. Temperature decidedly above normal. A cool wave on the 5th. Slight shocks of electricity were felt when the kites were at altitudes exceeding 800 meters. Wind NW; kites from NNW above 600 meters.

May 7. Sky clear. Temperature decidedly below normal, followed by a warm wave on the 8th and 9th. Electricity became unpleasant when the altitude exceeded 1,000 meters. Wind NE veering to ENE.

May 8. Sky clear except for a few cirrus and fracto-cumulus. Temperature above normal, and rising rapidly. The clock cylinder worked loose and the meteorograph record was lost after 3:30 P. M. Wind S; kites from SSW at highest point reached.

May 9. Sky about seven tenths covered with cirro-stratus and alto-cumulus. Temperature decidedly above normal and rising. Kites gradually shifted to the right as they ascended. Near the ground the top kites were from S, at 673 meters they were from W, and at 1,300 meters from NW. At an altitude of about 700 meters the electricity became so strong that it was necessary to ground the line.

May 14. Sky about two tenths covered with strato-cumulus or flattened cumulus. Temperature above normal. Wind SSW.

June 2. Sky partly covered with cumulus, rapidly decreasing in amount. Temperature near normal. Wind NW; kites continued from the same direction as the surface wind at the highest point.

June 6. Sky covered with stratus during the early morning and most of the afternoon. This broke up and partly disappeared between 9 A. M. and 2 P. M. Temperature below normal and falling. At 9:46 A. M., at an altitude of 470 meters, the kites entered the base of the fracto-stratus cloud. At 2:30 P. M. the lower kites entered the base of the stratus at a height of 424 meters, at 3 P. M. at a height of 422 meters, and at 4:53 P. M. were drawn out of the base of the stratus at an altitude of 412 meters. The instrument was above, and hidden by the cloud, during the greater part of the flight. Wind ENE; kites from E above 400 meters.

June 11. Sky partly covered with cumulus. Temperature below normal. Wind WNW.

June 12. Sky partly covered with high strato-cumulus. Temperature below normal, and stationary. Wind N.

June 13. Sky nearly covered with alto-stratus, and rain followed during the night. Temperature below normal, and falling. Wind ESE backing to E; kites from SE above 300 meters.

June 17. Sky nearly covered with alto-stratus, with a few fracto-nimbus beneath. Temperature near normal. Electricity on the line became strong when the kites reached an altitude of about 490 meters. Wind SSW.

June 29. Sky partly covered with cumulus. Temperature normal. At 3:45 P. M., when the instrument was at an altitude of about 1,300 meters, the line broke at a splice, and the four upper kites and the instrument were carried away. After travelling nearly five kilometers, the lower kite caught, keeping the upper kites flying and the instrument in the air until the kites were pulled down. No serious injury resulted. Wind WSW.

July 3. Sky covered with stratus. Cool wave; temperature 8° below normal. At 3:50 P. M., at an altitude of 423 meters, the kites and instrument entered the cloud. Wind E.

July 10. Sky partly covered with cumulus and cirro-stratus. Warm wave; temperature about 9° above normal. No electricity noticed at the highest point, but slight shocks felt in the descent when the instrument was at an altitude of about 785 meters. Wind WSW.

July 20. Sky covered with alto-stratus and cumulus, changing later to strato-cumulus. Temperature near normal and rising. At 10:38 A. M., and at an altitude of 841 meters, the kites entered the base of a fracto-cumulus. After this, cumulus continued driving over and hiding the kites occasionally. Electricity was very strong at the highest point. Wind SW backing to SSW. At 1:50 P, at the altitude of 938 meters, when descending, the kites suddenly shifted 28° of azimuth to the left.

July 22. Sky nearly covered with a sheet of alto-cumulus, and partly covered at a lower level with a sheet of strato-cumulus. Temperature above normal. At 2:33 P. M. the

kites entered the base of the strato-cumulus at an altitude of 605 meters. At 5:18 P. M., at an altitude of 670 meters, the meteorograph was drawn below the base of the strato-cumulus. During most of the flight the instrument was occasionally hidden by the low clouds. Wind SSW backing to S.

July 23. Sky clear except for a few cumulus. Temperature near normal but falling rapidly, due to the approach of a cool wave. Two flights were made. In the first one the line was pulled in to remove a defective kite. Wind WNW veering to NW; during the two flights the kites continued from the same direction as the surface wind.

Aug. 1. Sky clear except for a few cirro-cumulus. Temperature below normal. At the highest point reached electricity was moderately strong. In descending, one of the bolts on the drum was broken by the crushing strain of the wire. The wind backed from W to S during the ascent. The kites shifted rapidly to the right while ascending, and at the highest point pulled from NW when the surface wind was from S.

Aug. 17. Sky partly covered with cumulus. Temperature near normal. Electricity became strong at 900 meters altitude. A sea breeze set in on the hill as the kites reached the ground. Wind NNW veering to N; kites shifted to the right as they ascended, and at 900 meters were 16° of azimuth to the right of the surface wind.

Aug. 22. Sky partly covered with alto-cumulus and broken nimbus or strato-cumulus. Light sprinkles of rain during the ascent. Temperature near normal, and rising. The instrument entered the base of the nimbus at an altitude of 1,207 meters. Wind SSW; kites shifted to the right as they ascended, and above 1,100 meters were 30° to 36° of azimuth to the right of the surface wind.

Aug. 26. Sky partly covered with cumulus. Temperature near normal. Electricity on the line was strong when the instrument was above 1,300 meters. Wind S backing to SSE; kites shifted to the left as they ascended, and at 1,400 meters were 25° of azimuth to the left of the surface wind.

Aug. 31. Sky partly covered with fracto-cumulus, which changed later to cumulo-nimbus, with light showers in the afternoon. Temperature below normal. At 1,273 meters the instrument entered the base of the fracto-nimbus cloud. After the highest point was reached, and about 600 meters of wire wound in, the wind became too light to support the kites, and the entire line of them settled to the ground. The instrument and upper kites were found uninjured 2,500 meters from the Observatory. Wind SW; kites shifted to the right as they ascended, and at 2,000 meters were 58° of azimuth to the right of the surface wind.

Sept. 8. Sky covered with cirro-stratus. Temperature below normal. Pull of the kites on the line unusually steady. Wind NE and ENE; kites shifted to the right as they ascended, and at 1,300 meters were 20° of azimuth to the right of the surface wind.

Sept. 11. Sky clear except for a few cirrus. A warm wave; temperature about 12° above normal. Wind S; kites shifted to the right as they ascended and at 600 meters were about 40° of azimuth to the right of the surface wind.

Sept. 16. Sky nearly covered with strato-cumulus. Temperature below normal. Moderate shocks of electricity felt when the meteorograph reached 520 meters. The meteorograph entered the base of the cloud at an altitude of 590 meters, in the ascent, and came out of the cloud, in the descent, at 486 meters. Wind ENE; kites 38° of azimuth to the right of the surface wind at 576 meters.

Sept. 17. Sky nearly covered with strato-cumulus. Temperature near normal. When the altitude of about 1,000 meters was reached, the electricity became unusually strong. The kites and instrument entered the base of the strato-cumulus at a height of 840 meters. The kites were drawn out of the base of the cloud, in the descent, at an altitude of 900 meters. At 762 meters, in descending, the kites suddenly shifted to the left. Wind SSW veering to SW; kites 44° of azimuth to the right of the surface wind at 1,000 meters.

Sept. 18. Sky partly covered with cirrus. Temperature above normal. Wind NW; kites some 10° of azimuth to the right of surface wind at 900 meters.

Sept. 19. Sky nearly covered with dense cirro-stratus and low strato-cumulus. Temperature near normal but falling. The kites were in the cloud, and the meteorograph remained suspended in the base of the strato-cumulus from 3:53 to 4 P. M. at an altitude of 403 to 425 meters. Rain began at 6:35 P. M. Wind SSW; kites 35° of azimuth to the right of the surface wind at 400 meters.

Sept. 20. Sky clear except for a few fracto-cumulus. Temperature below normal. At 1,000 meters the electricity became strong. Wind WNW; kites 45° of azimuth to the right of the surface wind at 2,200 meters.

Sept. 24. Sky nearly covered with strato-cumulus. Temperature below normal but rising rapidly. Wind very variable, and it was difficult to maintain the kites in the air. Wind NW and WNW.

Sept. 25. Sky partly covered with cirro-stratus. Temperature near normal. Wind SE veering to SSE.

Sept. 29. Sky nearly covered with stratus. Temperature above normal and rising. Kites and meteorograph entered cloud at an altitude of 930 meters. The clock cylinder of the meteorograph was jerked off and the record lost after 5:40 P. M. Wind SE; kites shifted to the right as they ascended.

Oct. 6. Sky covered with low strato-cumulus. Temperature considerably below normal. At 11:25 A. M. the kites and instrument entered the base of the strato-cumulus at an altitude of 471 meters. At 11:45 A. M. instrument in the lower edge of the cloud at an altitude of 513 meters. At 11:54 instrument re-entered cloud at an altitude of 519 meters. At 0:42 P. M. instrument in the base of the cloud at an altitude of 602 meters. Wind NNE; kites shifted to the left as they ascended, and above 500 meters were 30° to 34° of azimuth to the left of the surface wind.

Oct. 8. Sky partly covered with cumulus at the beginning of the flight, which later changed to strato-cumulus, covering almost the entire sky during the afternoon. Temperature decidedly below normal and falling slowly. The meteorograph entered the cloud at 1:58 P. M. at an altitude of 1,358 meters. The meteorograph sank below the base of the clouds at 2:39 P. M., 2:58 P. M., and 3:34 P. M.; but during much of the flight it was hidden by the

clouds, and was only seen occasionally through the breaks between the clouds. In the morning, after 11 A. M., the kites were wound in to remove a defective kite, so that only 700 meters of line remained out. At 0:31 P. M. a second ascent was begun. At 1:45 P. M. the kite line was grounded on account of the intensity of the electricity on the line. Wind WNW; kites continued to shift to the right throughout the flight.

Oct. 31. Sky partly covered with cumulus decreasing in amount. A warm wave; temperature about 20° above normal. Electricity on the line moderately strong at the highest point reached. The instrument was partly torn from its fastenings by the diving of the kites, and the record lost after 4:50 P. M. Wind WNW and NW; kites shifted to the left as they ascended, and above 1,000 meters were 30° of azimuth to the left of the surface wind.

Nov. 17. Sky clear at the beginning of the flight except for a few fracto-cumulus; but these soon changed to strato-cumulus, which partly covered the sky. A warm wave; temperature nearly 20° above normal. At 3:31 P. M. the meteorograph and upper kites entered the base of the cumulus, at an altitude of 1,572 meters, but the kites immediately afterward dived and fell below the cloud. Wind W and WNW; kites shifted to the right as they ascended, and above 1,200 meters were 22° to 24° to the right of the surface wind.

Nov. 18. Sky covered with a uniform sheet of stratus. Temperature lower than on the 17th, but still considerably above normal. On account of the light wind, one kite was sent up about 500 meters before attaching a second kite and the meteorograph. The meteorograph entered the base of the stratus at 0:31 P. M., at an altitude of 513 meters, and continued visible in the base of the cloud until 0:47 P. M., when the wind became light and the kites sank to the ground. During the flight, from the time the meteorograph was attached until it was taken off, the highest kite remained in a strong upper current from the southwest, while the lower kites were in a current from the northeast. As a result of this pull on the line from opposite directions, it was carried up at a very steep angle. The meteorograph did not reach the upper current.

Nov. 30. Sky covered with stratus. A cold wave; temperature 8° to 10° below normal and falling rapidly. The kites did not reach the stratus clouds, the wind being too light above to lift the kites. At 11 A. M. a break occurred in the cloud, when it was seen that the top of the cloud was moving from the southwest across the face of the sun, while the base of the cloud was from the north or north-northeast. The wind was N and NNW throughout the flight. The altitude of the cloud was found, by reflected light during the evening, to be about 880 meters.

Dec. 12. Sky partly covered with cirrus. A warm wave; temperature above normal and rising. Two flights were made, one in the morning, the other in the afternoon. At the highest point reached in the afternoon, the meteorograph entered a warm and very dry current from the west. Wind SW.

Dec. 15. Sky covered with strato-cumulus. Temperature below normal, and falling. At 2:23 P. M. the kites, with the meteorograph, entered the base of the strato-cumulus at an altitude of 710 meters, and became invisible, except at 2:26 to 2:27 P. M., when they were seen in a break in the clouds. At 2:36 P. M. the kites had fallen below the cloud. Wind ENE; kites shifted to the right as they ascended and at 600 meters were 26° of azimuth to the right of the surface wind.

1897.

Jan. 2. Sky covered with stratus, which cleared away between 2 and 5 P. M., leaving the sky partly covered with cirrus. Temperature above normal and rising rapidly, due to the approach of a warm wave. The kites and meteorograph entered the base of the stratus at 11:55 A. M., at an altitude of 522 meters. After 0:01 P. M. the kites and instrument were hidden by the cloud until it began to break away at 1 P. M. The altitudes during this time were taken from the barograph. Electricity quite strong at an altitude of 160 meters. At greater altitudes it became weaker. After passing through the stratus at a height of about 700 meters, the meteorograph showed a remarkable rise in temperature and a fall in humidity. Wind SW; kites shifted to the right as they ascended, and entered a current from the west at about 700 meters altitude.

Jan. 19. Sky clear. A cold wave; temperature 20° below normal. The wind was so strong at the highest point reached by the kites that it was considered wise not to go higher. Wind NW and WNW; kites continued throughout the flight from nearly the same direction as the surface wind.

Feb. 9. Sky partly covered with fracto-cumulus. Temperature above normal but falling. Wind NW; kites continued throughout the flight from nearly the same direction as the surface wind.

Feb. 10. Sky clear except for a few fracto-cumulus. Temperature near normal but falling rapidly, due to the approach of a cold wave. Electricity weak, and only observed at the highest point reached. Wind NW; kites continued from nearly the same direction as the surface wind up to about 1500 meters, then shifted suddenly 18° of azimuth to the right.

NOTE. — The direction of the wind is that of the surface wind on Blue Hill, and the altitudes are above the Valley Station, 180 meters below the summit of the Hill, unless otherwise stated.

TABLE XIX.

SPECIMEN OF OBSERVATIONS AT THE WINDLASS.

AUGUST 26, 1896.

Time P.M.	Line out.	Meteorograph.		Pull of Kites.	Time P.M.	Line out.	Meteorograph.		Pull of Kites.	Time P.M.	Line out.	Meteorograph.		Pull of Kites.	Time P.M.	Line out.	Meteorograph.		Pull of Kites.
		Alt.	Az.				Alt.	Az.				Alt.	Az.				Alt.	Az.	
	meters.	°	°	kg.		meters.	°	°	kg.		meters.	°	°	kg.		meters.	°	°	kg.
4:02					4:47	1500	36.0	−20		5:19	2000	39.0	−27	20	6:14	3400	25.8		
4:11	500	43.2			4:48	"	36.5	−21		5:21	"	38.8	−27		6:15	"	25.8		
4:12	"	40.7			4:49	"	37.8	−21		5:22	"	38.8	−25		6:21	"	26.5		
4:13	"	44.3		11	4:50	"	36.8	−21		5:24	"	38.5	−25		6:22	"	26.5		
4:14	"	37.5			4:52	"	37.2	−22		5:25	"	38.6	−25		6:27	"	26.6		
4:15	"	36.7	0		5:00	2000				5:26	"	38.4	−24		6:29	"	27.0		
4:20	1000	14.0	−5		5:01	"	28.4	−22		5:27	"	38.6	−25		6:42	"	26.5		
4:22	"	36.3			5:02	"	30.6	−22		5:35?	2700	30.5			6:59	"			20
4:23	"	37.5			5:03	"	31.9	−22	23	5:44	"	31.4	−18		7:15	"			21
4:24	"	39.0	−18		5:05	"	34.4	−23		5:45	"	31.5	−18		7:20	"			22
4:25	"	38.8	−22		5:06	"	33.5	−23	16	5:46	"	31.6			7:55	"		−17?	20
4:26	"	38.7	−21		5:07	"	32.8	−22		5:48	"	31.9		20	8:08	"			20
4:27	"	39.9	−19		5:08	"	33.6	−22	18	5:56	3400	25.0			8:10	"			20
4:28	"	39.9	−18		5:09	"	34.5	−24		6:01	"	27.0			8:52	2000			23
4:29	"	36.8	−17		5:11	"	33.5	−23		6:03	"	26.6			8:58	"			
4:30	"	37.8	−15		5:12	"	34.9	−24		6:04	"	26.4			9:09	1500			
4:37	1500				5:13	"	35.2	−25		6:05	"	26.2			9:13	"			18
4:39	"	32.3	−14		5:14	"	35.4	−25		6:06	"	26.7			9:23	1000			16
4:40	"	34.3	−16		5:15	"	35.5	−26	20	6:07	"	27.0			9:28	"			
4:43	"	36.3	−19		5:16	"	37.0	−27		6:10	"	26.4			9:37	500			17
4:44	"	37.2	−21		5:17	"	38.5	−27	23	6:11	"	26.7			9:42	"			
4:45	"	36.4	−21	10	5:18	"	38.7	−27		6:13	"	26.5			9:54			−25	

NOTE. — The line out is the length of wire from the windlass to the meteorograph. Minus azimuths indicate that the kites shifted to the left as they ascended.

REMARKS.

From 3:50 to 3:55 P the kite meteorograph swung from the tripod wire for comparison with the Observatory instruments. 4:02 P the kite meteorograph left the ground lifted by a six-foot and a nine-foot modified Eddy kite. 4:40 P electricity first noticed on the line. 4:52 P added a six-foot kite and let out line. 5:27 P added a six-foot kite and let out line. From 6:03 to 6:15 P the angular altitudes were read on the top kite, 35 meters beyond the meteorograph. These readings were made simultaneously with theodolite observations at the ends of a 2590 meter base line, the object of which was to determine the height of the kite by triangulation. It became too dark to see the meteorograph after 6:42 P, and no further readings of the angular altitudes were possible. 6:45 P electricity strong. 8:10 P began to reel in the line. 9:54 P the meteorograph reached the ground and was hung on the tripod from 9:56 to 10:09 P for comparison with the Observatory instruments.

The wind was from the S at the beginning of the flight, but backed to the SSE about 6 P. M. and continued from that quarter until the end of the flight. The kites shifted to the left as they ascended, as shown by the readings in the azimuth columns. The wind velocity varied between 4.5 and 9.5 meters per second during the flight.

III. — Discussion of the Records.

By H. Helm Clayton.

Accuracy of the Observations.

The value of the results derived from the kite meteorograph depends largely on the accuracy with which the altitudes of the instrument, from moment to moment, are determined; therefore this accuracy demands first consideration.

Fortunately, the errors in determining altitude are found to be small, and affect the results to no greater extent than the instrumental errors of the meteorograph itself affect them. Our usual method of finding the altitude, when the meteorograph is visible, is by the formula

$$A = (\sin h)\ lx\,;$$

in which A represents the altitude; h, the angle above the horizon read by an altazimuth instrument placed near the reel; l, the length of line from the reel to the meteorograph, read from the dial; and x, a constant quantity determined experimentally as a correction for the sag of the line, and for other incidental errors. If the meteorograph is not visible, as, for example, at night, or when hidden by a cloud during the day, the altitudes are taken from the barograph trace, which is arranged to give altitudes graphically for the mean air temperature of 32° F. These altitudes, corrected for the observed air temperature, are taken as the true altitudes. When the fall or rise of temperature with height above the ground is shown by the meteorograph in its ascent to be uniform, the mean of the temperatures recorded simultaneously at the meteorograph and at the ground is taken as the mean temperature of the air column, and is used in the corrections of the altitudes by the barometer. But when the change of temperature with height is not uniform, as, for example, when the temperature rises till a certain altitude in the air is reached and then falls with increase of altitude, the means of the temperatures at the extreme points are taken. These means are then weighted in proportion to the lengths of the air column between these points, in order to get the mean temperature.

To describe the process more explicitly. The mean of the temperature recorded at the ground and at the place of highest temperature is taken; then the mean of the highest temperature and that recorded at the kite is taken; the two means are weighted in proportion to the vertical distance in each case; then, from these, a final mean is obtained which is used for the correction of the height given by the barometer. The chief error in taking the altitudes from the barograph arises from the contracted scale necessarily used, and from the breadth of the trace due to the vibration of the recording pen, caused by the kites. On this account, as well as on account of the instrumental error of the barograph and the uncertainty, at times, of the proper temperature correction, the error of getting the altitude from the barograph is considerably greater than by the method of using the angular altitude of the meteorograph and the length of line from the reel.

To determine the accuracy of the two methods by a third and independent method, and to obtain the correction x for sag of line, etc., in the first method, simultaneous measurements of the altitude of the kite meteorograph, or an adjacent kite, were made, from time to time, with the theodolites used for the measurement of cloud heights. In most of these measurements the length of the base line was 1,178 meters; but in two cases, August 26 and December 12, 1896, the base line was 2,590 meters in length; and in the first two cases, August 26 and 27, 1895, it was 100 meters. After correcting for instrumental errors, the formula used for computing the height is

$$Z = \tfrac{1}{2}\begin{cases} z_1 = b \sin a_2 \,(\operatorname{cosec} a_1 - a_2) \tan h_1 \\ z_2 = (b \sin a_1 \,(\operatorname{cosec} a_1 - a_2) \tan h_2) - C; \end{cases}$$

in which a_1 and h_1 and a_2 and h_2 are the azimuths and the angular altitudes of the kite meteorograph observed from the two stations respectively; b is the length of the base line; C is the difference in level between the two ends of the base line; z_1 and z_2 are the computed heights by the two methods; and Z, which is assumed to be the correct height, is the mean of z_1 and z_2.

In Table XX., column 1 gives the altitudes in meters computed from simultaneous theodolite measurements at the ends of a base line. Column 2 gives the altitudes computed from the formula

$$Z = (\sin h)\, l,$$

in which $\sin h$ is the angular altitude of the meteorograph or of a kite measured from the reel, and l is the length of line to the object. Column 3 gives the height computed from the barograph carried by the kites. This includes a correction for the mean temperature of the air column, and a correction for the height of the kite above the barograph when a kite was selected for measurement. In a few cases,

TABLE XX.

COMPARISON OF ALTITUDES BY DIFFERENT METHODS.

Date.	Hour.	1 Altitude by Theodolites.	2 Altitude by Angle and Line.	3 Altitude by Barograph.	4 Column 2 minus Column 1. Meters.	4 Per Cent.	5 Column 3 minus Column 1. Meters.	5 Per Cent.
1895.		meters.	meters.	meters.				
Aug. 26	3:53 P	400	394	. . .	− 6	−1	. . .	. . .
	5:09 P	452	468	. . .	+16	+4	. . .	. . .
	5:10 P	463	481	. . .	+18	+4	. . .	. . .
	Means	438	448	. . .	+10	+2.3	. . .	. . .
Aug. 27	5:28 P	611	620	. . .	+ 9	+1.4	. . .	. . .
1896.								
June 6	10:09 A	368	365	. . .	− 3	−1	. . .	. . .
	10:10 A	391	380	. . .	−11	−3	. . .	. . .
	10:11 A	330	345	. . .	+15	+4	. . .	. . .
	10:12 A	323	330	. . .	+ 7	+2	. . .	. . .
	Means	353	355	. . .	+ 2	+0.6	. . .	. . .
	0:21 P	554	578	. . .	+24	+4	. . .	. . .
	0:22 P	596	604	. . .	+ 8	+1	. . .	. . .
	0:25 P	574	586	. . .	+12	+2	. . .	. . .
	0:26 P	590	598	. . .	+ 8	+1	. . .	. . .
	0:27 P	610	616	. . .	+ 6	+1	. . .	. . .
	Means	587	597	. . .	+10	+1.7	. . .	. . .
June 19	3:24 P	842	853	. . .	+11	+1	. . .	. . .
	3:26 P	790	821	. . .	+31	+4	. . .	. . .
	3:27 P	730	763	. . .	+33	+5	. . .	. . .
	3:29 P	740	738	. . .	− 2	0	. . .	. . .
	3:30 P	703	730	. . .	+27	+4	. . .	. . .
	Means	761	781	. . .	+20	+2.6	. . .	. . .
June 29	3:19 P	1031	1070	1098	+39	+4	+67	+6
	3:20 P	1046	1085	1102	+39	+4	+56	+5
	3:21 P	1035	1060	1070	+25	+2	+35	+3
	Means	1037	1072	1090	+35	+3.4	+53	+5.1
July 10	3:27 P	731	734	762	+ 3	+0	+31	+4
	3:28 P	729	732	767	+ 3	+0	+38	+5
	3:29 P	712	726	753	+14	+2	+41	+6
	3:30 P	714	728	713	+14	+2	− 1	−0
	3:31 P	682	686	705	+ 4	+1	+23	+3
	Means	714	721	740	+ 7	+1.0	+26	+3.6
1896.		meters.	meters.	meters.				
Aug. 1	4:30 P	1736	1832	. . .	+96	+5	. . .	. . .
	4:32 P	1759	1821	. . .	+62	+3	. . .	. . .
	4:33 P	1772	1826	. . .	+54	+3	. . .	. . .
	4:34 P	1782	1837	. . .	+55	+3	. . .	. . .
	4:36 P	1878	1892	. . .	+14	+1	. . .	. . .
	4:37 P	1870	1933	. . .	+63	+3	. . .	. . .
	Means	1800	1857	. . .	+57	+3.2	. . .	. . .
	4:38 P	1961	1982	. . .	+21	+1	. . .	. . .
	4:39 P	1934	2056	. . .	+122	+6	. . .	. . .
	4:40 P	2010	2080	. . .	+70	+3	. . .	. . .
	4:41 P	2015	2065	. . .	+50	+2	. . .	. . .
	4:42 P	2031	2065	. . .	+34	+1	. . .	. . .
	4:43 P	1981	2046	. . .	+65	+3	. . .	. . .
	Means	1989	2049	. . .	+60	+3.1	. . .	. . .
Aug. 26	6:07 P	1501	1552	1578	+51	+3	+ 77	+5
	6:10 P	1474	1521	1558	+47	+3	+ 84	+6
	6:11 P	1493	1537	1558	+44	+3	+ 65	+4
	6:13 P	1492	1526	1538	+34	+2	+ 46	+3
	6:14 P	1436	1488	1538	+52	+3	+102	+8
	6:15 P	1478	1526	1578	+48	+3	+100	+8
	Means	1479	1525	1558	+46	+3.1	+ 79	+5.3
Dec. 12	3:00 P	605	609	618	+ 4	+1	+ 13	+2
	3:01 P	620	616	626	− 4	−1	+ 6	+1
	3:02 P	620	626	626	+ 6	+1	+ 6	+1
	3:03 P	619	612	618	− 7	−1	− 1	−0
	3:06 P	601	607	606	+ 6	+1	+ 5	+1
	Means	613	614	619	+ 1	+0.2	+ 6	+1.0
1897.								
Jan. 2	3:51 P	925	950	876	+25	+3	− 49	−5
	3:52 P	918	945	872	+27	+3	− 46	−5
	3:53 P	924	945	876	+21	+2	− 48	−5
	3:54 P	917	945	872	+28	+3	− 45	−5
	Means	921	946	874	+25	+2.7	− 47	−5.1

the highest kite was selected for measurement, because it was impossible to see the meteorograph from one of the theodolite stations. Column 4 gives the difference between column 2 and column 1 in meters and in percentages of the height. Column 5 gives the difference between column 3 and column 1. In the first two

flights in 1895, and on June 19, 1896, no barograph was carried by the kites. On June 6 and August 1, 1896, the trace made by the barograph at the time of the measurements was too faint to be read, although the loss of such records is rare. Comparison of column 1 and column 2 shows that the agreement is closer than with column 3, notwithstanding the fact that no correction is made in column 2 for the sag of the line. By classifying, according to height, the mean differences between column 2 and column 1, we obtain

TABLE XXI.

COMPARISON OF MEAN ALTITUDES OF THE KITE METEOROGRAPH.

Date. 1895–96.	Mean Altitude by Theodolites.	Difference between Theodolites and Angle of Meteorograph and Length of Line.		Difference in Per Cent for each 200 Meters.		Difference in Per Cent for each 500 Meters.	
	meters.	*meters.*	*per cent.*				
June 6	353	+ 2	+0.6	300	+1.5	0	+1.5
Aug. 26	438	+10	+2.3	500		500	
June 6	587	+10	+1.7	500	+1.1		
Aug. 27	611	+ 9	+1.4	700			
Dec. 12	613	+ 1	+0.2	700	+1.8	500	+1.8
July 10	714	+ 7	+1.0	900		1000	
June 19	761	+20	+2.6	900	+3.0	1000	+3.2
Jan. 2	921	+25	+2.7	1100		1500	
June 29	1037	+35	+3.4	1300	+3.1		
Aug. 26	1479	+46	+3.1	1500			
Aug. 1	1800	+57	+3.2	1700	+3.1	1500	+3.1
Aug. 1	1989	+60	+3.1	1900		2000	
Mean			+2.1				

This table shows that, in the average, the altitudes computed from the angle and the length of the line exceed the altitudes measured by theodolites about 2 per cent of the height. In this difference are included such errors as may exist in the recording apparatus, as well as the error arising from the sag of the kite line. The dial for recording the amount of line unrolled was tested by running lengths of 100 meters over the registering wheel; and the indications were found to be correct within less than 1 per cent, except in the earliest apparatus, in which the error was somewhat greater. The circles of the altazimuth instrument used for measuring the angular altitude of the kites were divided to half-degrees, and were read to tenths of degrees. The instrument was subject to slight errors; but these were made as small as practicable. Hence the excess of 2 per cent is believed to be due chiefly or entirely to the sag of the line.

Professor C. F. Marvin, in his mathematical analysis of the forces acting on the kite and line, computes that the percentages of slack (or sag) under varying conditions practically attainable range between 0 and 5 per cent, averaging somewhat less than 2 per cent (Monthly Weather Review, U. S. Weather Bureau, July, 1896, p. 252). With a number of kites on the line, as in tandem flying, the amount of sag would probably approximate this average. The results in Table XXI. show an increase in the percentages of difference between the heights by the two methods with increasing altitude. This may be due to errors in the methods of measurement, or to an increase in the amount of the average sag in the line. The increase, as shown by the last column in Table XXI., is about 1.6 per cent for the 1,500 meters between 250 and 1,750 meters, or the same between 400 and 1,800 meters, as shown by the fifth column. In other words, it is about 1 per cent for each 1,000 meters of ascent, so that, taking the excess of altitudes computed from the kite line as 1.5 per cent at 500 meters, it would be 2 per cent at 1,000 meters, and 3 per cent at 3,000 meters. In practice, it was decided to apply a correction of 2 per cent for altitudes below 1,500 meters, and a correction of 3 per cent for altitudes above this distance; so that the value of x in the formula becomes 0.98 in one case, and 0.97 in the other.

Returning now to Table XX., and subtracting 2 per cent from all the individual percentages in column 4 where the height was less than 1,500 meters, and subtracting 3 per cent where the height was above this distance, the average of the resulting figures is found to be ± 1.3 per cent. From this, according to Peters's formula, the probable error is about ± 1 per cent for any altitude computed from the formula

$$Z = (\sin h)\, l x.$$

This, however, includes the probable error of the theodolite measurements. If we assume the latter to be 0.5 per cent, the probable error in the measurements by the line and angle is ± 0.9 per cent. Hence the altitudes computed by the above formula, which comprise most of the observations, have a probable error of 1 per cent in round numbers, when the values of x given above are used. The probable error of the altitudes, measured by the barograph, is larger. From the residuals in Table XX. it is found to be between 3 and 4 per cent of the computed height.

The thermograph records are liable to several errors. The chief error arises from the exposure of the thermograph bulb. In the first thermograph, shown in Plate VIII., used from August 4, 1894, to September 21, 1895, the bulb was protected from insolation and radiation by arching a sheet of aluminium over the bulb, and enclosing the entire instrument in an inverted basket, through which the wind

could blow freely. Comparisons between the standard thermometer in the Observatory shelter and the records of the instrument, when swinging from the kites within 30 meters of the ground, showed that this exposure was fairly satisfactory.

In the meteorograph used from November 16, 1895, to April, 1896, and occasionally in May and June, 1896, (Plate IV. Figure 30,) the thermograph bulb was exposed beneath the instrument, and was well shaded, but the temperature was found to be considerably raised by insolation, perhaps on account of conduction of heat through the case. However, it is assumed that, at the small altitudes reached by this instrument, the insolation was virtually the same as near the ground, and that the correction required to reduce the readings to that of the standard thermometer in the shade, found when the instrument was near the ground and in full sunlight, can be applied to the records obtained at greater altitudes, in order to get the true air temperature. In other words, the condition remaining the same, it is assumed that the instrument recorded the correct fall or rise of temperature between successive altitudes. Hence the temperatures corrected to the Observatory standard by applying a correction determined at the beginning and end of each flight of the kites are given in Table XVII.

The records of the third meteorograph (Plate VIII.) begin with Table XVIII. With this instrument, a screen which is described by Mr. Fergusson and shown on Plate IV. Figures 35 and 36, was adopted after a number of trials of different forms, and it gives very satisfactory results. Two methods of testing the exposure were tried : —

1. The meteorograph was hung from a wire extending from the top of the Observatory to an adjacent tripod ; near noon, the point of support was moved backward and forward a few feet, so that the instrument was for a few minutes in full sunshine, and then for a few minutes in the shadow of the Observatory, but with scarcely any other change in environment. In both cases, the instrument was freely exposed to the breeze. The mean results of a number of cases show that the temperature averaged very slightly lower in the shade than in the sun.

2. The instrument was hung from the wire 2 or 3 meters above the ground in full sunlight, and in a moderate wind ; and the records were compared with the readings of a standard Fahrenheit thermometer in the thermometer shelter used at the Observatory. Following are the results of such a comparison, made August 13, 1896 : —

Time, P. M.	2:05	2:06	2:07	2:08	2:09	2:10	2:11	2:12	2:13	2:14	2:15	2:18
Thermometer	76°.5	76°.4	76°.3	76°.5	76°.7	76°.5	77°.0	76°.9	76°.7	76°.4	76°.4	76°.0
Kite thermograph	76°.1	76°.0	76°.0	76°.3	76°.9	76°.7	76°.7	76°.3	76°.1	76°.1	76°.1	75°.4

Both instruments were corrected for instrumental errors. The results show as close an agreement as could be expected in the case of instruments separated by a short distance. Comparisons were also made with Assmann's aspiration thermometer with almost identical results. It is customary to suspend the kite meteorograph on this wire, in the position described above, for a few minutes before and after every ascent, for the purpose of comparing its records with those made by the recording instruments at the Observatory. This is necessary because the jerking of the kites sometimes displaces the pen, and the irregular cutting of the record sheets and their hygroscopic character make the position of the datum line uncertain. The differences found between the standard instruments and the records of the kite meteorograph are applied as corrections to the latter. In this way, numerous comparisons were made. When the comparisons were made in full sunshine near the warmest part of the day, and were made also on the same days after sunset, the results show that the bulb of the kite meteorograph was well screened from insolation. If the comparisons were made first when insolation was in excess, and then when radiation was in excess, it is assumed that the mean of the two series gives the instrumental error of the kite meteorograph. After applying this correction for instrumental error to the thermograph, the following figures show the differences, in degrees Fahrenheit, between the readings of the kite thermograph and the readings of the Observatory thermograph exposed in the usual shelter and corrected to the readings of a standard thermometer: —

1896. Aug. 1	2:05 P	+0°.1	Aug. 26	3:55 P	+0°.2	Oct. 8	9:30 A	+0°.1	Nov. 17	2:00 P	0°.0
	6:51 P	−0°.1		10:09 P	−0°.2		9:15 P	−0°.0		6:07 P	0°.0
1897. Jan. 2	11:38 A	+0°.6	Feb. 10	3:00 P	+0°.9						
	5:54 P	−0°.6		6:53 P	−0°.9						

The sign + indicates that the corrected reading of the kite thermograph was higher than the standard; the sign — indicates that it was lower than the standard. The results show a slight amount of heating by insolation, but I think this is partly explained by reflection of heat to the bulb from objects near the ground. A final test of the exposure is found in the fact that, at altitudes exceeding a kilometer, almost exactly the same temperatures were recorded at the same altitudes before sunset as after sunset. This will be brought out subsequently in the discussion of the diurnal period.

The next error of importance to which the thermograph record is liable is the sluggishness of the thermometer. Numerous tests, made during the winter by taking the thermograph from a heated room into the open air, showed that the thermograph trace fell some 20° to 30° F., and recorded within two or three tenths

of a degree of the true air temperature within about three minutes. At the end of five minutes it assumed, virtually, the air temperature. When the fall of temperature was less, or the winds were high, these intervals were somewhat shortened. Hence, in practice, it is our custom, after letting out a certain amount of line, to allow the kites to rise to their maximum angular altitude. Then, when they have remained as nearly stationary as practicable from three to five minutes, they are sent higher by letting out more line. This serves also as an excellent check on the time errors of the meteorograph, and makes it possible to connect the temperature readings and the altazimuth readings, with comparative certainty. The temperature is read from the record at the end of the intervals, when the kites are nearly stationary. When the vertical motions of the kite are very great, the intervals when the meteorograph is nearly stationary for a few minutes are selected from the barograph record. These intervals can usually be connected with readings of the altazimuth instrument, in order to determine the altitudes with greater accuracy.

When records of wind velocity were obtained, it was customary to leave the kites near the same altitude for 10 to 15 minutes. To test the accuracy of the anemometer record, the meteorograph was suspended from the kites, and at the beginning or end of each ascent it was maintained, if possible, at the approximate height of the Observatory anemometer, long enough to record the velocity of the wind. The duration of the suspension was, in most cases, about 15 minutes; and the true velocities ranged from 4.5 to 10.3 meters a second, or from 10 to 23 miles per hour. The average velocity of the 20 comparisons is 7.8 meters per second (17.4 miles per hour). In the average, the kite anemometer differed from the Observatory anemometer 0.3 meter per second (0.6 mile per hour). This difference is between 3 and 4 per cent of the total velocity, — a difference not uncommonly found between two similar anemometers placed near together on the same tower.

The errors of the record of relative humidity, compared with a psychrometer, average about 5 per cent. There are individual errors of 10 per cent or more. The hairs in the instrument are very sensitive to the jerking of the kites, and were repeatedly thrown out of place. Thus the records of the hygrograph are less satisfactory than the others; but the results, corrected for instrumental errors, are believed to be approximately correct. They at least show the *directions* of the changes in humidity, if not the exact amounts.

Results from the Records of the Anemometer.

The records of the anemometer in the meteorograph which was lifted by the kites show that, as a rule, the wind increased steadily as the kites ascended. The

average difference between the wind at the kite and the wind on Blue Hill, for each increase of 100 meters above Blue Hill, is shown in the following table.

TABLE XXII.

INCREASE OF WIND VELOCITY FOR EACH 100 METERS ABOVE BLUE HILL.

Height above Blue Hill in meters	50 to 150	150 to 250	250 to 350	350 to 450	450 to 550	550 to 650	650 to 750	750 to 850	850 to 950
Average increase in wind velocity, meters per second	0.8	1.0	1.3	1.6	0.9	0.2	3.7	5.7	1.7
Average increase in wind velocity, miles per hour	1.7	2.2	2.9	3.5	2.0	0.4	8.2	12.7	3.8
Number of records	30	26	19	18	7	7	4	3	4

The rate of increase shown in this table for altitudes above 450 meters is irregular on account of the small number of observations. Between the average heights of 100 and 400 meters, the rate of increase of velocity for each 100 meters of greater altitude, was 0.3 meter per second, or 0.6 mile per hour. The rate of increase per 100 meters, found from the measurements of clouds in 1890 to 1891, for altitudes from 2,000 to 12,000 meters, was 0.27 meter per second in summer, and 0.65 meter per second in winter, making the mean 0.46 meter per second for the year. The records got with the kites were distributed throughout the year. Hence the results indicate that the rate of increase of velocity with altitude immediately above Blue Hill is less than that in the cloud levels at a greater height. Perhaps this may be caused by the influence of the hill. The excess of the average wind velocity recorded on Blue Hill over that recorded at the Weather Bureau station in Boston (ten miles north of Blue Hill) is 3.1 meters per second. The difference in level between the anemometers is 144 meters. This gives the exceptional increase in velocity of 2.1 meters for each 100 meters elevation. This condition is most naturally explained as a result of the retarding of the lower winds by friction against the ground. If it is assumed to arise from an undue excess of velocity immediately over the hill, then naturally the increase in velocity with greater altitude would be less than the normal until the kites rose entirely out of the influence of the hill into the normal conditions of the free air. However, the observations with kites are too few to settle the matter definitely. The results in Table XXII., added to the mean velocity at Blue Hill (7.2 meters per second), and the mean for Boston, are plotted in Plate V. Figure 3. The values above 400 meters are smoothed by taking the mean of each three successively. The individual records of the kite anemometer show wide variations. At times, the wind diminished with altitude, but at other times it increased so rapidly that the kites were unable to rise to great altitudes. On several occasions,

when the kites passed from one current into another of a different direction and of a different temperature, the wind showed a sudden increase of velocity, and was stronger at the place of meeting between the two currents than above or below that plane.

Changes in Direction of the Currents.

Differences in the direction of currents at different levels were shown by changes in the directions of the kites as they ascended. The kites usually shifted gradually toward the right as they ascended; but shifting toward the left was not uncommon. However, the most prominent tendency in changes of direction was for the kites to come into currents from the west as the kites ascended. Regardless of the direction from which the kites started, they usually shifted around into currents from the west when they reached considerable altitudes. This was especially marked with winds from the south, even when there was a strong barometric gradient at the earth's surface, causing winds from that direction. Such currents seem rarely to exceed a mile in depth. The diurnal current from the south, whose existence is shown by the diurnal rotation of the winds at Blue Hill, is very shallow. (See Discussion of the Cloud Observations, Annals of the Astronomical Observatory of Harvard College, Vol. XXX., Part IV. pp. 412–417.) When this current exists in the late afternoon, by the gradual shifting of the wind to the south, its upper limit rarely exceeds 200 meters above Blue Hill. Above this, the winds probably join in the more general diurnal period shown by the clouds. The law of change in wind direction evidently is, that, as long as the winds into which the kites enter are controlled by the general barometric gradient prevailing at the earth's surface, the deflection of the kites is toward the right as they ascend, provided that the velocity of the wind increases with increase of altitude, as is usual; but the kites are deflected toward the left when the wind velocity diminishes with increase of altitude. This effect is to be attributed to the earth's axial rotation. When the kites have ascended to a considerable height, they generally pass out of the influence of the winds caused by the barometric gradient at the earth's surface, and usually change their direction of flight more or less abruptly as they enter the current above. At times, however, the change of direction with increase of altitude is gradual until currents are reached which are almost diametrically opposite to those below. This occurred on April 13, at 6 P. M., when the lowest kite was from the south-southwest, and successively higher kites were more from the west, while the highest kites were from the northwest.

Results from the Thermograph Records of October 8, 1896.

A sample of the records of the kite meteorograph for August 26, 1896, is shown by a facsimile reproduction in Plate IV. Figure 29.

In order to study the changes of temperature and humidity with varying altitude, the records of the kite meteorograph, after being tabulated and corrected, were plotted according to altitude for each flight. On the same sheet were plotted in the same way the changes in azimuth of the upper kites, observed from the ground. A facsimile of the meteorograph record for October 8, 1896, appeared in the Monthly Weather Review of the United States Weather Bureau for September, 1896. A copy of the lines plotted as described above for that date is shown in Plate V.

Figure 4 shows the change of temperature with varying altitude, beginning with the second ascent at 0:31 P. M. The altitudes above the Valley Station are used, and the temperature is plotted according to the altitude of each record. When the kites were ascending, dots indicate the recorded temperature, and are connected by a continuous line. When the kites were descending ×'s indicate the recorded temperature, and are connected by a broken line. The same plan is followed in plotting the other elements. In the present case, the records during the ascent were obtained near the warmest part of the day; while the descent was made for the most part after sunset, the meteorograph reaching the ground shortly after 9 P. M. The two branches of the lines typify the temperature distribution vertically, as it is usually found in fair weather during the day and the night, respectively. In the continuous line representing the day observations, the temperature falls uniformly, and at the adiabatic rate, to the cloud level. In the broken line representing the night observations, the lower part of the line is decidedly curved, showing a body of relatively cold air near the ground, due to radiation from the ground. There is a rise of temperature with increasing altitude up to a given height, and afterward a comparatively uniform fall as far as the cloud level, if clouds exist; but the rate of fall with increasing altitude shown by the upper part of the diagram is slower at night than during the day. The lines show that the diurnal changes of temperature are very small at great altitudes, compared with the changes near the earth's surface. The lines connecting the temperatures, recorded at the same moment at the kites on the Hill and in the Valley, at or near the beginning of each hour, are given in Plate VI. Figures 1 and 2. They show the relation of the diurnal changes in the upper air to those in the lower air, in a way better than do the plotted lines in Plate V. The full lines connect observed values and the

dotted lines are extrapolated. Records are available for the night at the Hill and the Valley stations only; but after 10 A. M., records in the upper air are available from the kite thermograph for almost every hour up to 9 P. M. Figure 1 shows that after 10 A. M., at heights below 1,000 meters, the temperature of the air at all levels rose almost uniformly until 2 P. M. This rise may be explained by the ascent of the heated air from the earth's surface. The air, heated at the ground, in rising is cooled by expansion at the adiabatic rate, namely, about 1° C., or 1°.8 F., for each 100 meters of ascent in unsaturated air. Air descending to take the place of the rising body is heated by compression at the same rate; so that the entire atmosphere between the upper limits of the ascending columns, or when clouds exist between the base of the clouds and the ground, is found to cool with ascent at the adiabatic rate of unsaturated air, as shown by the lines after 10 A. M. for October 8 in Figure 1.

Now, if air, heated at the ground and cooling by ascent at the adiabatic rate of unsaturated air, rises, say to 1,000 meters, its temperature will be 18° F. lower than when it left the ground. If an hour later the temperature has risen 2° F. at the ground, the air rising from the ground to 1,000 meters and cooling 18° F., as before, will be 2° F. warmer than was the air at the same level an hour previous. The same is true for any intermediate level; so that the entire atmosphere through which the ascending currents pass will be warmed at the same rate as the air near the ground. It is to be noted, however, that this does not occur until the ascending currents (and the consequent adiabatic rate of fall of temperature) are established; and it extends only to the tops of the ascending currents, which probably reach successively higher and higher altitudes as the day advances. It follows that the highest levels reached by the ascending currents partake of the progressive rise of temperature only for a short time preceding the warmest part of the day. Hence they change their temperatures but little. The tops of these ascending currents are well outlined on fair days by the tops of the cumulus clouds; and these tops, which are usually found below 2,000 meters, show the upper limit of the diurnal heating which may arise from this cause. The full lines for 6 A. M. and 7 A. M. in Figure 1 show that, at these hours on October 8, the temperature was lower in the Valley than on the Hill. Between 7 A. M. and 8 A. M., there was a rapid rise in temperature at the Valley Station, and the adiabatic rate, indicating the formation of ascending currents, was established between the upper and the lower station. The dotted lines, extending the full curves, are intended to show what was the most probable distribution of temperature above the Hill during the early morning. Soon after 2 P. M. the temperature at the ground and at the kites ceased to rise, and in Figure 2 are drawn

lines connecting the temperatures recorded near the beginnings of the afternoon and the evening hours at the kites, on the Hill, and at the Valley Station. These lines show that the adiabatic rate of change of temperature between the ground and the kites was departed from immediately after the warmest part of the day; and that the difference in temperature between the kites and the ground became rapidly less, on account of the quick fall of temperature at the ground, while the temperature at the higher levels fell very slightly. The fact that the adiabatic rate of fall of temperature between the ground and the kites ceased about 3 P. M. (the records in each case being used only when the kites were below the base of the clouds), indicates that the ascending currents from the ground ceased about this time. Yet the clouds formed by these ascending currents persisted until after 6 P. M., but were almost entirely gone by 7 P. M. This delay in clearing may be explained partly by the delay required for the ascending currents to reach the cloud level. But since the temperature aloft must continue to rise until the warmest air which leaves the ground arrives, and since the maximum temperature near the cloud level was reached about 3 P. M., or shortly after, the delay in the cessation of cloud formation on this account could not have been long. It seems evident that the clouds existed for two or three hours after the cessation of the ascending currents by which they were formed. The successive measurements of the altitudes of the cloud bases, by kites entering or leaving the clouds, show that the bases of the clouds rose rapidly until the warmest part of the day, and then sank slowly. This is shown in the following observations, in which the first height is taken from the humidity curve, the kites not being seen actually to enter the cloud.

Time	11:18 A	1:58 P	2:05 P	2:39 P	3:01 P	3:34 P	3:56 P	4:34 P	4:57 P	5:23 P
Altitude in meters .	713	1178	1224	1341	1454	1408	1360	1344	1330	1370

This result agrees with the average of measurements made by theodolites on a large number of days in showing an increase in height of the bases of the cumulus until the warmest part of the day, and then a decrease.

It is probable that, after the ascending currents cease with the warmest part of the day, the cumulus subside slowly under the influence of gravity, and at the same time gradually dissipate. Cumulus, however, do not always cease to form after the temperature at the ground begins to fall in the afternoon. In some cases I have observed fresh cumulus forming after sunset, but such cases preceded cooler weather; and it is probable that the adiabatic rate persisted in the lower air on account of the rapid inflow of cooler air aloft, as explained below in the discussion of the vertical distribution of temperature in cold waves.

The vertical distribution of temperature on October 8 is further illustrated in Plate VI. by *isothermohyps* (equal temperature heights), a name suggested by Professor W. M. Davis. These curves are drawn by reading, from the lines in Plate VI. Figures 1 and 2, the altitude at which each temperature ending in 0° or 5° F. was found at each hour, and by plotting the altitudes with dots. These are then connected by continuous curves showing the changes in altitude of the given temperature during the course of the day. The chart shows near the ground a complex set of curves caused by the inversion of temperature with increase of altitude at night. But above 400 meters there is probably a simple diurnal curve with a single maximum and minimum, the range of which diminishes with increasing altitude, and probably above 2,000 meters reaches, or approximates, zero.

The conditions found on October 8 below the cloud level are typical of the conditions found on all fair days with cumulus clouds. The conditions above the cloud level on October 8 will be considered when discussing the temperature curve designated Type 4. However, the records indicate that a diurnal change in temperature exists at a greater altitude on days with cumulus clouds than on other days, when the ascending currents from the ground are weak or are prevented by some cause from reaching a great altitude.

Diurnal Changes of Temperature at Different Altitudes.

The isothermals drawn from the records of the kite meteorograph, illustrated in Plate VI., indicate that the maximum temperature at moderate altitudes in the free air occurs in the early afternoon, and the minimum occurs during the night. The same is shown by observations on mountain peaks. In other words, a curve representing the diurnal changes in the air at some distance above the ground is probably similar to one representing the changes near the ground, except that the amplitude is less. If this is true, then the diurnal rate of fall for any given time at any two levels will be proportional to the daily ranges of temperature at the two levels. Hence, if the average rate of hourly fall during the afternoon is known from simultaneous observations at any two levels, and the daily range is known for either level, then the daily range at the other level can be found by multiplying the known range by the ratio between the falls found at the two levels. It is impossible in practice to keep a kite at exactly the same level for 24 hours; hence the daily ranges for the different levels must be found by comparing the rates of rise or fall of temperature for given times with the rates found from records near the ground made simultaneously with those above. The records of the kite meteorograph were made chiefly during the afternoon. In order to get

the ratio of fall for the same intervals at altitudes of 500 meters and at the ground, the records made by the kite meteorograph near 500 meters, when the kites were ascending, are discussed below; also those made near the same level when the kites were descending. Cases are taken only when the meteorograph was approximately stationary long enough to take the true air temperature. Differences of level are corrected by reducing the temperature at the level farthest from 500 meters to that of the level of the record made nearest 500 meters. Thus, on August 26, 1895, records were made at 449 meters and 546 meters when the kites were ascending, and at 501 meters when the kites were descending. The fall

TABLE XXIII.

SYNCHRONOUS CHANGES OF TEMPERATURE NEAR 500 METERS, ON BLUE HILL AND AT THE VALLEY STATION.

Date.	Time. P. M.	Altitude of Kite above Valley.	Observed Change in Temperature			Change per Hour in Temperature		
			at Kite.	on Hill.	in Valley.	at Kite.	on Hill.	in Valley.
1895.	hrs. and min.	meters.	°F.	°F.	°F.	°F.	°F.	°F.
Aug. 26	3:46 – 5:37	501	−2.0	− 6.7	− 5.6	−1.0	−3.6	−3.0
Aug. 28	4:55 – 5:55	521	−3.0	− 3.0	− 4.9	−3.0	−3.0	−4.9
Dec. 21	2:56 – 4:14	473	−0.3	− 1.0	− 1.3	−0.2	−0.8	−1.0
1896.								
April 5	4:26 – 6:24	506	−1.9	− 3.5	− 3.7	−1.0	−1.8	−1.9
June 19	3:07 – 5:13	537	−0.4	− 1.9	− 1.0	−0.2	−0.9	−0.5
June 22	4:10 – 9:55	527	−4.9	−10.9	−13.1	−0.8	−1.9	−2.3
April 11	4:25 – 5:34	483	−5.2	− 2.7	− 1.8	−4.5	−2.3	−1.6
April 13	3:54 – 6:35	528	−1.8	− 9.6	−15.0	−0.7	−3.6	−5.6
April 24	3:07 – 5:05	501	−1.1	− 2.9	− 0.7	−0.6	−1.5	−0.4
May 7	3:04 – 5:17	558	+3.9	− 1.7	− 2.0	+1.8	−0.8	−0.9
May 9	2:36 – 4:43	524	+4.3	− 4.7	− 5.8	+2.0	−2.2	−2.7
June 2	4:20 – 6:23	480	−1.9	− 2.1	− 2.5	−0.9	−1.0	−1.2
July 10	2:56 – 4:10	520	−0.2	− 0.8	− 0.8	−0.2	−0.7	−0.7
July 22	5:02 – 5:18	490	−2.6	− 2.4	− 2.0	−0.5	−0.5	−0.4
July 23	1:43 – 6:15	510	−2.6		− 5.8	−0.6		−1.3
Aug. 26	4:13 – 9:42	511	−6.5	−13.1	−19.8	−1.2	−2.4	−3.6
Sept. 8	4:34 – 6:22	482	+1.4	− 2.0	− 3.8	+0.8	−1.1	−2.1
Sept. 16	1:01 – 4:09	520	+0.8	− 2.9	− 5.1	+0.3	−1.0	−1.6
Sept. 20	3:39–10:05	504	−4.8	−12.4	−18.7	−0.7	−1.9	−2.9
Sept. 25	3:26 – 5:56	500	−1.3	− 8.0	−11.2	−0.5	−3.2	−4.5
Oct. 8	0:31 – 8:50	551	−2.9	− 6.9	−14.3	−0.3	−0.8	−1.7
Nov. 17	2:42 – 5:04	473	−2.0	− 3.2	− 5.7	−0.9	−1.3	−2.4
Dec. 12	2:28 – 3:22	457	+2.0	+ 0.2	− 1.4	+2.2	+0.2	−1.6
1897.								
Jan. 2	0:01 – 5:32	524	+5.8	− 0.2	− 2.8	+1.5	−0.1	−0.5
Feb. 10	3:43 – 6:36	610	−2.2	− 5.9	− 7.0	−0.8	−2.1	−2.4
Means		512				−0.42	−1.60	−2.06

of temperature between 449 and 546 meters was 2°.8 F., or 0°.029 for each meter of ascent. Consequently, to correct for the difference in level of 52 meters between 501 and 449 meters, it is necessary to subtract 1°.5 from the temperature recorded at the altitude of 449 meters. Then in the 111 minutes elapsing between the times when the kites passed these altitudes in ascending and descending the fall of temperature was 2°.0. The fall of temperature during the same interval on Blue Hill was 6°.7 and at the Valley Station 5°.6; the rate of fall per hour at the three places being respectively 1°.0, 3°.6, and 3°.0 F. In this way, Table XXIII. is constructed to show the synchronous changes of temperature aloft and at the ground.

The mean rates of hourly change, given at the foot of Table XXIII., show that the rate of change at the Valley Station is 4.90 times as great as that at the kites; the change on the Hill is 3.82 times as great as that at the kites; and the change at the Valley is 1.27 as great as that on the Hill. Now, if the supposition is correct that these ratios are in proportion to the total daily ranges of temperature at the respective stations, then the total mean range at the Valley divided by 1.27 should give the range on the Hill, and divided by 4.90 should give the mean daily range at the kites. The mean daily range at the Valley Station, found from the observations for

TABLE XXIV.

SYNCHRONOUS CHANGES OF TEMPERATURE AND HUMIDITY NEAR 1,000 METERS, ON BLUE HILL AND AT THE VALLEY STATION.

Date.	Time. P. M.	Altitude of Kite above Valley.	Observed Change in Temperature			Change per Hour in Temperature			Observed Change in Humidity		Change per Hour in Humidity	
			at Kite.	on Hill.	in Valley.	at Kite.	on Hill.	in Valley.	at Kite.	on Hill.	at Kite.	on Hill.
1896.	*hrs. and min.*	*meters.*	°F.	°F.	°F.	°F.	°F.	°F.	*per ct.*	*per ct.*	*per ct.*	*per ct.*
April 13	4:43–6:20	899	+1.0	− 6.5	−10.8	+0.6	−4.0	−6.7				
May 9	3:04–4:15	1033	+4.2	− 3.0	− 2.0				− 5	+ 2	− 4	+2
June 6	1:56–4:00	1006	+0.4	− 3.8	− 2.6	+0.2	−1.9	−1.3	+ 5	+10	+ 2	+5
June 19	3:24–4:45	1000	+0.2	− 1.7	− 0.7	+0.1	−1.2	−0.5				
June 22	5:32–7:43	1024	−0.2	− 5.4	− 7.6	−0.1	−2.5	−3.5				
July 22	0:42–4:29	1160	−1.4	− 2.5	− 1.3	−0.4	−0.7	−0.4				
July 23	3:56–6:08	1025	−1.2		− 3.8	−0.5		−1.2	+ 7	+ 1	+ 3	+1
Aug. 22	3:28–5:31	1003	−0.1	− 1.8	− 0.6	0.0	−0.9	−0.3	−22	+ 9	−11	+4
Aug. 26	4:48–9:13	1041	−1.0	−11.0	−16.7	−0.2	−2.5	−3.8	−22	+31	− 5	+7
Oct. 8	0:59–8:24	1098	−1.0	− 6.6	−14.3	−0.1	−0.9	−1.9	−23	+20	− 3	+3
Nov. 17	3:02–4:32	1004	−0.7	− 1.8	− 3.5	−0.5	−1.2	−2.3				
1897.												
Jan. 2	3:16–4:27	1031	+0.6	− 2.0	− 2.6	+0.5	−1.7	−2.2	− 3	+ 6	− 3	+5
Feb. 10	4:20–6:16	990	0.0	− 4.0	− 5.5	0.0	−2.1	−2.9	− 5	+ 8	− 3	+4
Means		1024				−0.03	−1.78	−2.24			−3.0	+3.9

eight years at that place, is 20°.8 F.; this, divided by 1.27, gives 16°.4, and, divided by 4.90, gives 4°.2. The observed range at the summit of the Hill, from observations for eleven years, is 16°.7 F. Since this agrees very closely with the range computed above (16°.4), it seems fair to conclude that 4°.2 is also a close approximation to the true range at 500 meters. If the observed range at the summit of the Hill (16°.7) is divided by 3.82 (the ratio between the mean hourly changes found at the kites and on the Hill), then 4°.4 is obtained for the range at 500 meters. The mean of the two methods gives the range as 4°.3 F.

For altitudes of about 1,000 meters, Table XXIV. is constructed in the same manner as was Table XXIII. for altitudes of about 500 meters; except that changes of relative humidity are also included in Table XXIV.

These results, treated in the same way as the means in Table XXIII., show that the daily range of temperature at 1,000 meters is 0°.3. The result is the same, whether the ratio of change is taken from the Valley or the Hill Station.

These results show also that the diurnal range of temperature diminishes rapidly with increasing altitude in the free air, and almost disappears, on the average, at a height of 1,000 meters. Probably, however, it occasionally extends to altitudes of 2,000 meters. The average diurnal ranges (determined by direct observations and computed from the kite meteorograph records at different altitudes, counting from the level of the Valley Station, which is itself 15 meters above sea level) are as follows: —

	Valley Station.	Base Station.	Summit Station.	Kite.	Kite.
Diurnal Range in deg. Fahr.	20°.8	17°.8	16°.7	4°.3	0°.3
Altitude in meters	0	49	180	500	1000

The Base Station is at the foot of the northern slope of Blue Hill; beyond, the land slopes more gently to the Neponset River, near the banks of which is the Valley Station. With these ranges may perhaps be compared the range of 10°.1 F., obtained from observations for five years on the Eiffel Tower at an altitude of 300 meters, since this range no doubt approximates the true diurnal range in the free air at that height, and the range at the foot of the tower is approximately the same as the range at the base of Blue Hill.

These results are plotted for their respective heights in Plate V. Figure 1. The points are connected by a continuous line, and, besides, a smoothed curve is drawn through them. The smoothed curve passes approximately through every one of the observed and the computed ranges, except the one at the summit of Blue Hill, which is too great. This evidently is because insolation and radiation, acting through the soil of the hill, heat and cool the air to a greater extent than the free air is heated

and cooled at the same altitude. This must be true at every mountain station. The smoothed curve passes also very slightly to the left of the result for the Eiffel Tower, indicating that the range there is about 1° F. greater than the true range, on account of the heating and cooling of the tower. If the diurnal range for the altitude of the top of Blue Hill is taken from the smoothed curve in Figure 1, it is 12°.4 F., which is 4°.3 lower than the observed range.

Diurnal Changes of Relative Humidity at Different Altitudes.

In order to study the diurnal changes of relative humidity at different altitudes, Table XXV. is prepared from the records of humidity, in the same manner as Table XXIII. is made from the records of temperature.

TABLE XXV.

SYNCHRONOUS CHANGES OF RELATIVE HUMIDITY NEAR 500 METERS, AND ON BLUE HILL.

Date.	Time. P. M.	Altitude of Kite above Valley.	Observed Change		Change per Hour	
			at Kite.	on Hill.	at Kite.	on Hill.
1896.	hrs. and min.	meters.	per ct.	per ct.	per ct.	per ct.
April 11	4:25–5:34	483	+11	+ 2	+9	+2
April 13	3:54–6:35	528	+ 1	+13	+1	+5
April 24	3:07–5:05	501	− 1	+ 6	−1	+3
May 7	3:04–5:17	558	−14	+ 6	−6	+3
May 9	2:36–4:43	524	− 7	+ 3	−3	+1
June 2	4:20–6:23	480	+ 4	+ 2	−3	+1
July 10	2:56–4:10	520	+ 7	+ 3	+6	+2
July 23	1:43–6:15	510	− 3	0	−1	0
Aug. 26	4:13–9:42	511	+34	+40	+6	+7
Sept. 8	4:34–6:22	482	− 2	+14	−1	+8
Sept. 16	1:01–4:09	522	− 3	+ 8	−1	+3
Sept. 25	3:26–5:56	500	+15	+16	+6	+6
Oct. 8	0:31–8:50	551	− 9	+18	−1	+2
1897.						
Jan. 2	0:01–5:32	524	−24	+ 9	−4	+2
Feb. 10	3:43–6:36	610	+ 4	+ 9	+1	+3
Means		518			+0.6	+3.3
Diurnal Range					3.5	19.1

In computing the diurnal range, given at the foot of this table, the data are treated in the same way as described in connection with Table XXIII. No records of humidity were obtained at the Valley Station. The synchronous changes in relative humidity near 1,000 meters and on the summit of the Hill are given in Table XXIV., in which the means show reversed signs. In other words, as night approaches, the

humidity at the altitude of 1,000 meters diminishes, while at the earth's surface it increases. This agrees with the evidence furnished by the cumulus clouds which form during the day between 1,000 and 2,000 meters altitude, and which disappear at night, thus visibly indicating an increase of humidity by day, and a decrease by night. If the form of the humidity curve at a height of 1,000 meters is assumed to be the reverse of that found at the ground, then the results got from the kite meteorograph show a diurnal range of 14.7 per cent at 1,000 meters, with the minimum humidity at the coldest, and the maximum humidity at the warmest part of the day. These mean daily ranges for different altitudes are plotted in Plate V. Figure 2. The part of the plotted line at the left of the zero line shows the range at different altitudes, with the minimum humidity near the *warmest* time of day; while the part at the right of the zero shows the ranges at different altitudes, with the minimum humidity at the *coldest* time of day.

Types of Temperature Change with Altitude.

When the records of temperature and humidity, made aloft by the kite meteorograph and at the stations near the ground, are plotted in relation to altitude, and lines are drawn connecting the observed values, the resulting lines are found to be distinctly divisible into a few types. Examples of each of these types, plotted directly from the records on selected days, are shown in Plate VII.

Type 1, Plate VII., is plotted from the records of temperature on July 23, 1896. It represents the decrease of temperature on most fair days, from the ground to altitudes of a mile or more, when no clouds are met. On August 26 the ascent was made during the late afternoon between 4 and 6 o'clock, and the meteorograph, after remaining near the highest point for about two hours, was drawn down in the night between 8 and 10 o'clock. The continuous line, plotted from the records of the ascent, represents the day conditions, and the broken line, plotted from the records of the descent, represents the night conditions. This curve differs from the normal of this type only in the fact that the broken curve shows a higher temperature during the night than during the day, at altitudes above 1,100 meters. Observations, as previously shown (p. 103), indicate that no diurnal change exists at this altitude. However, with the approach of warmer or colder weather, the temperature continues steadily to rise or to fall during either night or day. This curve shows that with increasing altitude the temperature falls uniformly, and approximately at the adiabatic rate, during the day. The fall is strictly at the adiabatic rate, or about 1°.8 F. in unsaturated air, for each 100 meters of ascent, during the morning and early afternoon, as shown on October 8; but it begins

to depart from this rate in the late afternoon. The fall of temperature with increasing altitude in the night is much slower than in the day. In fact, from the earth's surface to an altitude of a few hundred meters, there is a rise of temperature with height, and the air at altitudes of from 300 to 500 meters is considerably warmer than at the ground.

When clouds are met during the flight, the temperature curve assumes the form of Type 2. This curve is plotted from the records of July 20, 1896, when both ascent and descent were in the daytime. The continuous curve is plotted from the records of the ascent; the broken curve, from the records of the descent. In the ascent, the base of the cumulus clouds was entered at a height of 866 meters above the Valley Station. In the descent, the instrument came out of the base of the cumulus at a height of 1,022 meters. The humidity record shows that the meteorograph passed out of the top of the cloud in the ascent at a height of about 1,100 meters, and re-entered the top of the cloud in the descent at a height of about 1,400 meters. The plotted line shows that the temperature fell, at the adiabatic rate in unsaturated air, till the level of the base of the cloud was reached. It fell at a slower rate while the instrument was in the cloud, the rate probably being that computed by physicists as the adiabatic rate for air in which condensation is taking place; but this could not be determined with accuracy, because the instrument was successively entering and leaving the sides of different clouds drifting across it. Above the clouds, the fall of temperature was very slow; but this condition may have been abnormal. At night, the curve representing Type 2 has the same form near the ground as Type 1.

Type 3, Plate VII., is drawn from the records of December 21, 1895. It is a type of curve which persists throughout the day and night; and it resembles the night form of Type 1. The ascent was made between 2:13 and 3:16 P. M.; and from the records the continuous line is plotted. The descent was made between 3:30 and 4:47 P. M., the instrument thus reaching the ground about thirty minutes after sunset. This descent gave the records from which the broken line is plotted. The records from the Blue Hill Base Station (49 meters above the Valley) are also included in the plotted lines. The lines show that the temperature rose very rapidly for a short distance above the ground, and then fell, as the height increased, at a rate somewhat less than the adiabatic rate. The rate of fall of temperature shown by the upper part of the curve obtained during the descent is slightly slower than that in the curve obtained during the ascent; and the rise of temperature near the ground with increasing altitude is much more marked after sunset than during the daytime. At 3:30 P. M., when the meteorograph was at the highest altitude (614

meters), the temperature was slightly lower at the Valley Station than at the kites; and the difference probably increased during the night. In the present case, which is probably characteristic, the highest temperature was found between 100 and 200 meters above the Valley Station; but on other occasions with this type of curve, as on November 17, 1895, the highest temperature was at altitudes of 400 meters, or slightly higher.

Type 4, Plate VII., is plotted from the records of the ascent on September 29, 1896. No records were obtained during the descent. This type is also represented by the temperature curves obtained on October 8, 1896, shown in Plate V., in which both the day and the night conditions are represented. This form of curve is produced by a warmer current overflowing colder air, — a condition which is very commonly found at low altitudes in the atmosphere, and probably exists usually at some altitude, great or small. It might perhaps be called the normal type of curve. This type may be found when colder air is pushing from the east or north near the ground beneath an opposing warmer current; but in a large majority of cases, when found below altitudes of 2,000 meters, it is caused by the approach of a *warm wave*, the upper air of which, partaking of the rapid movements of the upper currents from the west, advances faster than the lower part of the *warm wave*, and overflows the colder air in front. Hence this type may be called the *warm wave* type. A knowledge of its existence enables one to forecast the arrival of a *warm wave*, with a high degree of certainty, from eight to twenty-four hours in advance.

The characteristics of this type of curve are as follows: during the day a decrease of temperature, at the adiabatic rate, from the ground to an altitude of several hundred meters; then a sudden rise of temperature in the next 100 meters or 200 meters of ascent; and, afterward, a slow fall of temperature, with increasing altitude usually at a rate much less than the adiabatic rate. The rise of temperature in passing from the cold to the warm current may be as much as 25° to 30° F., as on January 2, 1897. The sky is sometimes clear when these conditions exist, as on April 13, April 27, May 9, August 1, and December 12, 1896; but usually clouds are found near the meeting of the warm and the cold current. Sometimes the clouds are in the warm current, immediately above the plane of meeting of the two currents; at other times, the clouds are in the cold current, immediately below the plane of meeting; and occasionally they seem to exist between the two currents. Clouds immediately above the plane of meeting of the two currents were found on February 13 and September 29, 1896; clouds immediately below the plane of meeting were found on October 8, November 18, 1896,

and January 2, 1897; clouds exactly between the two currents were found on November 23, December 9, 1895, and September 17, 1896.

At first, I was inclined to attribute these cloud formations to a mixing of the air in the plane between the two currents of different temperature; but a careful study shows that this cannot be the cause in many, if not most, of the cases. In the two cases where the clouds were above the plane of meeting of the warm and the cold current, the cloud sheets were very dense. On February 13, precipitation occurred at the time of the ascent, and continued during the day. On September 29, the hygrograph showed that the cloud was more than 700 meters thick, because the air continued to be saturated from the time when the hygrograph entered the cloud at 900 meters to 1,600 meters, — the highest point reached. Hence it is impossible to attribute the cloud formation to cooling by mixture with the lower current, because the air at the highest point reached was several degrees cooler than the top of the cool current beneath. Therefore it could not possibly have been cooled to the dew-point by admixture. The explanation of the cloud formation probably is that the plane of meeting between the currents was a slanting one, the cooler current being wedge-shaped; and that the warmer air, in moving upward along this slope, was cooled to the point of saturation by expansion. The cooler currents are sometimes wedge-shaped, as is shown by frequent observations from the top of Blue Hill of cooler currents, filled with fog, advancing against or retreating before warm southerly currents. In such a case, the southern edge of the cooler current is very thin, and does not extend higher than the tree tops; farther north, however, it grows gradually thicker, until the tops of the highest hills are hidden by the fog. Several cases of this kind are described in the Discussion of the Cloud Observations. (Harvard Annals, Vol. XXX. Part IV.) In such cases, the fog is probably produced by streaks of the warmer air drawn down into the cooler air by the invisible undulations, like ocean waves, between the two currents.

In the case of clouds beneath the plane of meeting of the currents, there were evidently several causes for cloud formation: ascending currents; mixture; conduction; and possibly other causes. The two following cases, namely, October 8, 1896, and January 2, 1897, illustrate these conditions.

On October 8, 1896, scattered fracto-cumulus began to form about 9 A. M. in the currents ascending from the ground, as on ordinary fair-weather days. When the temperature near the ground rose, the bases and the tops of these clouds were formed at higher and higher altitudes until about noon, when the tops of the ascending currents reached the base of the warmer stratum of air. Further ascent was stopped

as if by a wall, because even the warmest air in the colder current was denser and heavier than the air of the warmer upper current. The result was, that, when the tops of the clouds reached the plane of meeting between the currents, they began to spread out, and to join one another; so that by noon, and during the entire afternoon, the sky was covered with strato-cumulus, through the breaks in which the kites could be seen at intervals. The bases of these clouds, however, continued to rise until the warmest part of the day, because the diminishing relative humidity, as the heat increases, makes it necessary for the air columns to rise to greater altitudes before condensation begins. Toward evening, after the ascending currents had ceased, these clouds cleared away, as do ordinary cumulus.

On January 2, 1897, several causes appeared to be active in the cloud formation and its subsequent changes. The sky was covered with a dense uniform sheet of stratus until noon. The kite meteorograph passed through this stratus at noon. The record shows that the sheet was then 142 meters thick, and formed the top of a cold stratum of air. Immediately above this cold stratum, another stratum of air more than 25° F. warmer was found. In the ascent, the temperature decreased with altitude, at the adiabatic rate in unsaturated air, up to the cloud level; and there were evidences of ascending currents, because the clouds immediately afterward broke into strato-cumulus, which grew gradually thinner and almost entirely disappeared between 1 and 2 P. M. Evidently the causes of these phenomena are as follows. As soon as the ground became warmed by insolation (which is felt to some extent even through the densest clouds), ascending currents were formed. These compelled the simultaneous formation of descending currents, from the tops of which cloud matter was drawn downward and rapidly evaporated by warming in descent; at the same time, the clouds grew thicker at the top of the ascending columns by cooling in ascent, thus breaking the stratus into strato-cumulus. While the diurnal heating at the ground increased, the relative humidity, in consequence, diminished; the ascending air rose to higher levels before vapor condensation began, and the clouds grew thinner, because the tops of the ascending currents were limited to the lowest level of the warmer upper current. Finally, with increasing heat at the ground and with diminished humidity, the ascending currents rose to the level of the warmer current before condensation by expansion could occur; consequently, all cloud formation ceased in the lower level, leaving the sky clear, except for a few cirrus at a very great height. The sky remained clear during the warmest part of the day, but toward evening fracto-stratus began to form. By 7 P. M., the sky was again covered with a uniform sheet of stratus, which continued during the night. The descent of the kite meteorograph between 5 and 6 P. M., about an hour after sunset, showed that the adiabatic rate

of change of temperature with change of altitude, in the lower air, had disappeared; and the colder air stratum had nearly the same temperature from top to bottom. The question then is, What was the origin of the stratus cloud (then about 170 meters thick) which was again forming at the top of the cold stratum?

This stratus could not have been caused by an admixture in equal proportions of the warm and the cold current; because, first, the temperature of the cloud stratum was not a mean between the two currents; and, second, the relative humidity of the upper current (49 per cent) was too low for condensation to take place by complete admixture of the two currents. But the dew-point, or temperature of condensation in the warm current, was 37°, while the temperature at the top of the cold current was 34°. Hence it is evident that, if a thin layer of the warm current could have been cooled to the temperature of the lower current by the conduction of its heat to the lower air, then condensation of its moisture into a cloud might have occurred. However, this does not seem to satisfy the conditions, because the reverse of this was apparently taking place. For the base of the warmer current was found about 100 meters lower when the kite meteorograph descended than when it ascended; indicating that the top of the colder current was being warmed. The most satisfactory explanation of these conditions is that occasional thin sheets, or streaks, of the upper air were drawn down into the lower air by the tossing to and fro of the air in the wave-like agitation which was evidently in progress. The agitation was doubtless caused by friction between the two currents. These thin streaks may be cooled virtually to the same temperature as the lower air; so that the excess of moisture existing between the upper air dew-point and the lower air temperature would be condensed as cloud. It is analogous to the condensation of the breath emitted from the lungs in a cold morning. Such breath is cooled to the temperature of the air, and forms an evanescent cloud. It is true that enough of these streaks cooling to form a cloud sheet must, to a certain extent, raise the temperature of the lower air. This apparently was taking place on January 2, 1897, because the top of the colder air during the descent of the kites was found to be warmer than during their ascent. In whatever way the cloud stratum was formed in the night, further condensation must have been aided by radiation from the cloud. It should be mentioned in connection with this, that much the strongest wind encountered on January 2 (as proved by the pull of the kites) was in a thin stratum between the warm and the cold current. Both above and below this level the winds were weaker, and at the highest point reached they were barely strong enough to support the kites. The strong wind was also from a more westerly direction than was the wind above

or below it. The clouds found between a warm and a cold stratum, as on November 23 and December 9, 1895, are in all probability clouds of mixture.

The days when this type of vertical distribution of temperature was found without cloud formation were evidently days when the humidity of both air strata was too low for clouds to form, either in the ascending currents from the ground, or by mixture between the currents. One of these days, April 13, 1896, furnishes an interesting example of the breaking up of this vertical distribution of temperature. On this day, between 9 and 10 A. M., during the ascent (see Table XVII.), a much higher temperature than that at the ground was found at an altitude of about 500 meters. On the descent of the kite meteorograph, about three hours later, between noon and 1 P. M., this abrupt rise of temperature at a height of about 500 meters had disappeared, and the temperature was found to decrease from the ground to the highest point reached by the kites. Between 3 and 4 P. M., fracto-cumulus began to form at a considerable altitude, and soon covered a large part of the sky. The probable explanation is that the intense insolation near the ground, uninterrupted by clouds, rapidly raised the temperature of the ground and the adjacent air; so that the heated air, carried up by the ascending currents, had by noon become slightly warmer than the air at 500 meters. Hence the ascending currents were able to penetrate the upper stratum. Up to that time the ascending current had been stopped by the warmer current above; no cloud formation was possible, because the lower air was relatively dry, and the altitude of the warm upper current was too low for condensation to take place from cooling by expansion in the lower ascending currents. But after the ascending currents had once penetrated the upper stratum, the air there was caught in the descending currents which brought to the ground the increasing warmth imported by the warm wave coming from the west. This aided the insolation in increasing the temperature at the ground, so that the diurnal maximum temperature was prolonged until about 4 P. M. It is usually found two hours earlier at Blue Hill. It seems probable that this vertical distribution of temperature (shown by Type 4) is usually broken up in this way. That this is not the only method, however, seems to be proved by the sudden rises of temperature which sometimes occur in the night. In forecasting the daily weather, the value of a knowledge of this form of temperature distribution seems apparent; because on it depend the answers to the questions whether clouds of certain kinds can be formed; what changes existing clouds can undergo; what shall be the distribution of the diurnal cloudiness; whether cumulus clouds will be flattened, or whether they will form towering clouds; and hence whether showers are possible or not.

The reverse of Type 4, that is, a sudden fall of temperature at a given altitude due to a colder current overlying a warmer one, is probably impossible, because the colder air, on account of its increased weight, would immediately begin to sink, and the warmer air to rise. This would cause the fall of temperature to take the adiabatic rate from the ground to the top of the colder current. This is probably the process of origin of Type 5, Plate VII., which is characteristic of *cold waves*. The example given is plotted from the records in the *cold wave* of January 19, 1897. The continuous curve is plotted from the records of the ascent, and the broken curve from the records of the descent. The parts of the curves oscillate somewhat from side to side; but the mean result shows a fall of temperature with increase of altitude, at the adiabatic rate of unsaturated air, from about 300 meters to the highest point reached. Below 300 meters, the rate of decrease of temperature is more rapid than the adiabatic rate. This is the especial characteristic of the *cold wave* type of curve during the day hours. The excessive rate of decrease of temperature below 300 meters probably results from two causes: first, on account of the freer movements of the upper currents, colder air is moving in aloft more rapidly than at the ground, so that air rising from the ground is not only cooled by expansion, but also by contact with colder air aloft; second, the air coming in contact with the ground is heated more rapidly than usual. This latter condition results not only because the sun shining through the dry, cloudless, dust-free air of the *cold wave* causes greater heating of the ground by insolation than normal; but also because the ground is warmer than the air from the fact that the air of the *cold wave* is colder than the normal temperature of the latitude in which it is found. The night form of Type 5, notwithstanding the excessive radiation from the ground through the dry air, shows a rapid decrease of temperature with increase of altitude from the ground upward. In this way it differs decidedly from Type 1 and Type 2. This fall of temperature with increase of altitude is not so rapid near the ground in the night as in the day; but it is apparently at the adiabatic rate in dry air (1°.8 F. in 100 meters). If for any night on which the temperature fell rapidly as a result of an approaching *cold wave* the thermograph records at the Blue Hill Valley Station and at the summit of Blue Hill are corrected for instrumental errors, and are placed one over the other, the curves will be parallel, and the temperatures at the summit will be found lower than at the Valley Station by almost exactly 3° F., which is the adiabatic rate of decrease between the two stations. At least, this condition was found in an examination of the records during a number of well marked *cold waves*. Hence, with such conditions, it seems possible for cumulus clouds to exist all night; and even for thunder-showers to occur, if the lower air

is damp enough. This sometimes happens during the night at the beginning of a *cold wave.* In fact, the formation of the *cold wave* type of curve is probably the cause at any time of day of severe thunderstorms and of other local storms. It is well known that tornadoes are generally connected with a decided fall of temperature in the northwest quadrant of the cyclone within which the tornadoes are formed; and that thunderstorms are usually followed by colder weather. On account of the rapid flow of the upper currents, which may bring the advancing upper edge of the cold wave over warmer air, these conditions attending local storms favor the formation of the *cold wave* type of curve, such as was shown by our kite records on the afternoon of August 31, 1895, preceding an energetic thunderstorm on the evening of the same day.

Type 6, Plate VII., plotted from the records of the kite meteorograph for September 8, 1896, shows a less common but an interesting form of vertical distribution of temperature, in which the temperature was virtually the same from 400 to 1,400 meters or more. In other words, there is no change, or a very small change, of temperature with increasing altitude above 400 meters or thereabout. Below this level, Type 6 shows the same form as Type 1 and Type 2; that is, a fall of temperature with increasing altitude during the day, and a rise with increasing altitude at night. These last conditions can be readily traced to the effects of insolation and radiation near the ground. Suppose, for example, that at a certain hour of the morning the temperature of the air were the same from the ground up to 1,000 meters or more. (The thermograph records at the Valley and at the Summit Station show that this occurred at 8:15 A. M. on September 8.) After this time the temperature at the ground will rise because of the heating by insolation. The air next the ground, being heated by contact, will rise and cool by expansion until it assumes the temperature of the air aloft, which is not then heated. This process must continue until the maximum temperature of the day is reached. On September 8, the rise of temperature from 8:15 A. M. to the maximum temperature of the afternoon at the Valley Station was 8° F. Hence, at the warmest part of the day, the air next the ground, rising and cooling at the rate of 1°.8 F. for each 100 meters of ascent, would rise to 444 meters before falling to the temperature observed at 8:15 A. M., which is assumed to be the mean temperature of the upper air column. In almost every case of this type of curve, the limit of the adiabatic rate of fall, and hence of the ascending currents during the day hours, was found to be near 400 meters; which shows that the conditions of September 8 were normal conditions. At night, cooling takes place by radiation next the ground. It is gradually transmitted upward a few hundred meters by conduction, thus producing an increasing

temperature with increasing altitude. Before sunrise on the morning of September 8, the temperature was 8° F. warmer at the top of Blue Hill than at the Valley Station. As a result of the conditions described, it is evident that, on days like that under consideration, the diurnal range of temperature is not felt above 500 meters, unless the upper air itself is directly heated by insolation and cooled by radiation; but observation proves that this does not take place except to a very small degree.

Examples of the different types are found on the following days: —

Type 1. September 21, 1895; May 4, June 19, June 22, June 29, July 23, August 26, and November 17, 1896.

Type 2. March 11, July 20, July 22, and August 31, 1896.

Type 3. November 23, December 21, and December 26, 1895; January 12 and February 23, 1896.

Type 4. December 9, 1895; February 13, April 13, April 18, April 27, May 9, August 1, September 17, September 29, October 8, December 12, 1896; and January 2, 1897.

Type 5. August 31, November 20, November 27, November 30, December 12, 1895; January 27, February 17, December 15, 1896; and February 10, 1897.

Type 6. (*a*) March 6, (*b*) April 15, (*c*) April 24, (*d*) May 7, (*e*) May 20, (*f*) June 6, (*g*) September 8, and (*h*) November 30, 1896.

In most of the short ascents the curves are probably those of Type 1 and Type 2; but the altitudes reached were too low to determine to which type each curve belongs.

Types of Humidity Change with Altitude.

The different types of humidity curves, showing the changes of humidity with altitude, derived from the records of the kite meteorograph, are given in Plate VII. These curves are plotted from the records on selected days, in order to show each type. As in the preceding plates, the continuous lines represent the records of the ascent, and the broken lines represent the records of the descent.

Type 1 and Type 2 may be called the normal types of curves when clouds are present. Type 1 is plotted from the records of August 31, 1896. On this day, the ascent was shortly before noon, and is shown by the continuous curve. There are no records of the descent. Hence, the broken curve is plotted from the records of other dates in order to illustrate the night form of the curve. Type 2 is plotted from the record of October 8, 1896, and is shown in Plate V. It differs from Type 1 in showing in its upper part a fall of humidity rather

than a rise. The form which the curve takes at night had not become fully established at the time of the descent on October 8, but it is probably like the form given in Type 1. These two types of curves can be described as the normal types of change of humidity with change of altitude in cloudy or partly cloudy weather. The humidity increases steadily after leaving the ground until the base of the cloud is reached ; then the hygrograph shows complete saturation, or 100 per cent. This condition continues to the top of the cloud ; then occurs a sudden and marked fall of humidity as the meteorograph passes into the dry air above the cloud into which the ascending currents from the ground have not penetrated. After entering this dry air, the hygrograph sometimes shows a fall and sometimes a rise of humidity with increasing altitude, as represented in Type 1 and Type 2.

Type 3, plotted from the records of August 1, 1896, is a clear-weather type of curve in which the humidity rises until a certain altitude is reached, probably at the upper limit of the currents ascending from the ground. Above this altitude, the humidity falls rapidly.

Type 5, plotted from the records of January 19, is also a clear-weather type ; and since this type occurs almost exclusively on the same days as Type 5 of temperature, it is numbered the same. In other words, the clear-weather type is the accompaniment of *cold waves*, in which very dry descending air is mingled with air rendered damp by ascent. The result is a nearly uniform relative humidity at different altitudes, though of course the absolute humidity diminishes with increasing altitude on account of the diminishing pressure and temperature.

Type 6 is plotted from the records of September 8, 1896. In this type, both the relative and the absolute humidity diminish rapidly with increasing altitude, except very near the ground and during the daytime when ascending currents are in progress. Its dates of occurrence coincide almost exactly with the dates of Type 6 of temperature. It is therefore numbered in the same way. As shown in the next section, this type of temperature and humidity is found near the central area of anticyclones. In Types 1 to 3, the absolute humidity remains nearly stationary, or falls slowly until the cloud level, or the point of maximum relative humidity, is reached ; after this, it falls rapidly.

Positions of the Different Types of Vertical Distribution of Temperature in Cyclones and Anticyclones.

In order to ascertain the relation of the types of vertical distribution of temperature to cyclones and to anticyclones, the position of the centre of the cyclone

or the anticyclone prevailing at the time when the kite ascended is taken from the map of the United States Weather Bureau for the given date, or from the map of tracks in the Monthly Weather Review. The numerals representing the different types shown in Plate VII. are then plotted in a chart in their proper position as regards the centre of the cyclone and the anticyclone. These charts are shown in Plate I. Figures 3 and 4. The small figures represent the numbers of the different types. The figures in parentheses accompanying Type 3 show in meters the approximate altitudes of the maximum temperature, which in this type occurs at a moderate distance above the ground. The figures in parentheses accompanying Type 4 show in meters the approximate altitude of the sudden rise of temperature found in this type. The letters in parentheses accompanying Type 6 refer to the letters on page 114, accompanying the date of each example of this type. They are for use in reference, on account of the interest of this type. The small circle with a dot in it, near the middle of each chart, gives the position of the centre of the cyclone or the anticyclone. Distances are shown by the scale at the foot of the charts. The average width of the cyclonic and the anticyclonic circulation of the wind is shown in these Annals, Vol. XXX. Part IV., Plate XIV. Figures 2 and 5.

Type 1 does not appear on the charts; in other words, it is non-cyclonic in its character.

Type 2 occurs in the cyclone to the east and southeast of the centre, but is not found in the anticyclone.

Type 3 occurs exclusively in the southeast quadrant of the cyclone; and the continuous curve encloses all the cases observed. Type 3, however, was observed only in the winter half-year; during the summer half-year it was replaced by Type 2.

Type 4 and Type 5 were found chiefly within anticyclones, and Type 6 was found entirely within them. These types occur in groups in different positions about the centre of the anticyclone. Straight lines are drawn in the chart to separate the groups.

Type 5, the *cold wave* type, is found chiefly in the southeast quadrant of the anticyclone. Two cases occurred south of the centre of the cyclone, slightly in advance of the position where Mr. R. DeC. Ward found the maximum frequency of thunderstorms in cyclones over New England. (Harvard Annals, Vol. XXX. Part IV., Plate XIV. Figure 6.) Type 3 and Type 5 follow opposite courses near the ground, one showing a rise of temperature with altitude above the ground; the other showing an abnormally rapid fall. It is interesting to note that Type 3 is

found in the southeast quadrant of cyclones, and Type 5 in the southeast quadrant of anticyclones. In both cases, the position is such that the winds are crossing the lines of latitude nearly perpendicularly. (Harvard Annals, Vol. XXX. Part IV., Plate XIV. Figures 2 and 5.) In the first case, the winds are moving from a warmer to a colder latitude, and hence are chilled by contact with the colder ground; in the second case, the winds are moving from a colder to a warmer latitude, and hence are abnormally warmed by contact with the ground.

Type 6 is of especial interest on account of its form and position, and its bearing on the theory of the anticyclone. The records of the kite meteorograph, as illustrated by these curves (Plate VII. Type 6), show the same conditions aloft near the central area of anticyclones as are found at the meteorological observatories of Europe; namely, a warm and very dry air. The observations at the Alpine observatories, and especially on the Sonnblick, have been ably discussed by Dr. Hann. The warm and extremely dry air at altitudes of a kilometer and higher, near the centre of anticyclones, is generally explained as being the result of the warming of the air by descent and consequent compression. This explanation demands that the air shall be heated by descent at the adiabatic rate. In other words, in ascending into the air the temperature should fall at the adiabatic rate. This condition might be modified near the ground by cooling from radiation of heat to the ground, by contact with the ground, or by conduction of heat to the ground, provided that in each case the ground is cooler than the air. But during the daytime, when the ground, and the air immediately above it, are warmer than the mean temperature of the air column, as shown by the lower part of the curve of September 8 (see Plate VII. Type 6), these supposed modifying causes entirely fail to explain the matter. Hence, with the condition of no temperature change with change of altitude, shown by the records of the kite meteorograph, either there can be no descending current below 1,500 meters near the centre of the anticyclone, or there is some cause (or causes) other than those given above which counteract the dynamic heating of the air by descent.

Mr. R. DeC. Ward, with whom I discussed the diagrams, suggested the cause to be the mixing of air currents of different temperatures. The temperature of the air on the east side of the central area of the anticyclone changes with change of altitude, at the adiabatic rate approximately; on the west side, it changes at the adiabatic rate during the warmest part of the day up to a certain altitude, where there is a sudden rise of temperature, and above that altitude a slow decrease with increasing altitude. It is possible that these two conditions,

in which a fall of temperature with increasing altitude is the prevailing characteristic, could, at their place of meeting, bring about a condition of no change of temperature with change of altitude. But it is difficult to understand the processes. It is also difficult to conceive of the mixture of ascending and descending currents in the central area of the anticyclone without adiabatic change with change of altitude. The overflow of air in the anticyclone appears to demand a descending current near the central area. But since this seems inconsistent with the condition of no change of temperature with change of altitude, there appears as yet no adequate explanation of the condition; and especially so, since the air is known to cool with extreme slowness by radiation. The radiation into space would be more effective at the high altitudes from which the air starts than near the ground. Furthermore, on some of the days showing this type, as on September 8, the sky was covered with cirro-stratus; yet the condition of no change or a very slow change of temperature with change of altitude in the positions shown by Type 6 in Plate I., Figure 3, remained the same as on clear days.

Changes of Temperature with Altitude in Cyclones and Anticyclones.

The distribution around the centres of cyclones and anticyclones of the types of temperature change with change of altitude shows, in a general way, the differences of temperature between any given levels in different parts of the cyclone and the anticyclone. In order to study the differences more in detail, charts were made to show the differences between each 300 meters of altitude. Since the changes of temperature with altitude during the day differ from those during the night, and the changes with altitude during the winter differ from those during the summer, the number of charts showing all the conditions is considerable, and it is not deemed expedient to publish them. The striking features brought out by them are that southeast of a line running from southwest to northeast, and passing about 400 kilometers to the east of the anticyclone centre, the fall of temperature with increasing altitude in the anticyclone is faster than in any part of the cyclone; and it approximates, or slightly exceeds, the adiabatic rate in unsaturated air. Within 300 meters of the ground around, and 500 kilometers to the southeast of the centre of the anticyclone during the day, the rate of fall of temperature with increasing altitude equals 2°.6 F., or 1°.5 C., for each 100 meters of altitude, this being the greatest rate of fall yet recorded. Northwest of a line running from northeast to southwest and passing about 400 kilometers west of the centre of the anticyclone, the temperature was found to be higher at all altitudes from about 300 to 1,000 meters

than it was at the same time at the ground. The western limit of this area of high temperature aloft was not shown in the charts.

Over a considerable area, central about 800 to 1,000 kilometers southeast of the centre of the cyclone, the temperature at the height of 300 meters during the winter half-year was higher than at the ground; and during the summer half-year, the rate of change of temperature with change of altitude was usually less than the adiabatic rate. Between the altitudes of 300 and 600 meters, the rate of change of temperature during the day was found to approximate very closely to the adiabatic rate in unsaturated air; except that over an area to the east of the cyclone centre, where rain was falling and cloud formation had begun below 600 meters. (See area of nimbus cloud in average cyclone, Harvard Annals, Vol. XXX. Part IV., Plate IV. Figure 2.) Few records were obtained above 600 meters to the east and north of the cyclone centre; but in these few cases cloud formation had begun between this altitude and 1,000 meters, and the change of temperature with change of altitude was slow. A number of records between 600 and 1,000 meters was obtained south of a line passing about 500 kilometers south of the centre of the cyclone. In most of these, the change of temperature with change of altitude during the day approximated to the adiabatic rate.

Vertical Gradient of Temperature on Days with Cumulus Clouds.

Cumulus clouds have frequently been explained as originating in the heated air which rises from the ground, and which is cooled by expansion till its contained vapor is condensed. If this is true, the ascending air must cool at the adiabatic rate, and the air which descends to take its place must also be heated by descent at the adiabatic rate; thus it is of interest to determine how near this rate of change of temperature with change of altitude is shown by the records on days when cumulus clouds prevailed.

Table XXVI. gives the differences in temperature, and also the rates of change of temperature per 100 meters, between the Valley Station and the kite meteorograph, when the latter was about 500 meters high on days with cumulus clouds. Table XXVII. gives the differences and the rates of change on days with cumulus clouds when the kite meteorograph was about 1,000 meters high. By classifying the rates of decrease per 100 meters in Table XXVI. and Table XXVII. according to the hours of the day, Table XXVIII. is obtained, where the rates in Table XXVI. are also classed according to season.

TABLE XXVI.

CHANGES OF TEMPERATURE WITH ALTITUDE FROM 0 TO ABOUT 500 METERS, ON DAYS WITH CUMULUS CLOUDS.

Date.	Hour.	Alt. of Kite above Valley.	Temp. Diff. Valley to Kite.	Rate per 100 Meters.	Date.	Hour.	Alt. of Kite above Valley.	Temp. Diff. Valley to Kite.	Rate per 100 Meters.	Date.	Hour.	Alt. of Kite above Valley.	Temp. Diff. Valley to Kite.	Rate per 100 Meters.
1895.		met.	°F.	°F.	1896.		met.	°F.	°F.	1896.		met.	°F.	°F.
Aug. 20	11:20 A	452	− 7.7	−1.7	May 4	3:20 P	480	− 8.3	−1.7	Sept. 16	10:28 A	511	−12.7	−2.5
Aug. 24	0:46 P	540	− 9.8	−1.8	May 7	3:04 P	558	−12.4	−2.2	" 16	1:23 P	478	−10.0	−2.1
" "	1:03 P	483	− 9.2	−1.9	" "	5:17 P	568	− 6.6	−1.2	Sept. 19	3:53 P	425	−10.9	−2.6
Aug. 26	3:57 P	546	− 7.4	−1.4	May 8	3:13 P	472	− 9.7	−2.1	Sept. 20	3:39 P	463	− 9.0	−1.9
" "	5:37 P	501	− 3.2	−0.6	May 14	4:58 P	559	− 7.6	−1.4	" "	10:05 P	504	+ 4.2	+0.8
Aug. 28	4:45 P	488	− 6.4	−1.3	June 2	4:20 P	560	−10.5	−1.9	Sept. 25	3:01 P	537	−14.2	−2.6
Aug. 31	0:05 P	487	−10.2	−2.1	" "	6:23 P	480	− 9.0	−1.9	" "	5:56 P	500	− 3.6	−0.7
Sept. 21	2:18 P	533	− 7.8	−1.5	June 11	5:21 P	534	− 9.8	−1.8	Oct. 8	10:16 A	611	−10.1	−1.7
1896.					June 29	2:29 P	381	− 7.4	−1.9	" "	11:39 A	528	− 8.6	−1.6
Jan. 27	3:33 P	558	−10.2	−1.8	July 10	2:56 P	520	− 9.2	−1.8	" "	0:31 P	551	− 9.0	−1.6
Feb. 8	5:29 P	491	− 5.8	−1.2	July 20	2:38 P	484	−10.0	−2.1	" "	8:50 P	650	+ 1.3	+0.2
Feb. 12	5:34 P	562	− 8.8	−1.6	July 23	1:43 P	548	−10.0	−1.8	Oct. 31	2:47 P	498	− 8.4	−1.7
Feb. 17	4:40 P	525	−11.0	−2.1	" "	2:45 P	482	−10.0	−2.1	" "	3:58 P	418	− 5.3	−1.3
Apr. 5	4:26 P	506	− 9.1	−1.8	" "	3:36 P	478	− 9.0	−1.9	Nov. 17	2:42 P	473	− 7.6	−1.6
" "	6:24 P	548	− 7.7	−1.4	" "	6:15 P	510	− 6.5	−1.2	" "	5:04 P	467	− 3.8	−0.9
June 18	5:21 P	578	−11.8	−2.0	Aug. 17	11:00 A	556	− 9.4	−1.7	1897.				
June 19	2:42 P	492	−10.4	−2.1	Aug. 26	4:13 P	511	−10.1	−2.0	Feb. 9	3:10 P	605	−12.3	−2.0
" "	3:07 P	572	−11.1	−1.9	" "	9:42 P	560	+ 2.6	+0.5	" "	3:48 P	552	− 9.2	−1.7
" "	5:13 P	537	−10.0	−1.9	Aug. 31	10:16 A	496	−12.8	−2.6	Feb. 10	3:39 P	576	−10.5	−1.8
Apr. 13	3:54 P	528	− 9.4	−1.8	Sept. 11	4:54 P	475	− 5.5	−1.2	" "	6:36 P	640	− 6.7	−1.0
May 4	2:18 P	533	− 9.3	−1.8	" "	5:31 P	471	− 1.4	−0.3					

TABLE XXVII.

CHANGES OF TEMPERATURE WITH ALTITUDE FROM 0 TO ABOUT 1,000 METERS, ON DAYS WITH CUMULUS CLOUDS.

Date.	Hour. P. M.	Alt. of Kite above Valley.	Temp. Diff. Valley to Kite.	Rate per 100 Meters.	Date.	Hour. P. M.	Alt. of Kite above Valley.	Temp. Diff. Valley to Kite.	Rate per 100 Meters.	Date.	Hour. P. M.	Alt. of Kite above Valley.	Temp. Diff. Valley to Kite.	Rate per 100 Meters.
1896.		meters.	°F.	°F.	1896.		meters.	°F.	°F.	1897.		meters.	°F.	°F.
Apr. 13	5:23	1060	−12.0	−1.1	July 23	3:53	1065	−17.7	−1.7	Jan. 19	0:12	1011	−19.9	−2.0
" "	6:02	1089	− 5.7	−0.5	" "	6:08	863	−11.6	−1.4	Feb. 9	3:30	1018	−18.6	−1.8
May 4	4:50	827	−16.0	−1.9	Aug. 17	0:06	940	−15.9	−1.7	Feb. 10	4:20	990	−16.2	−1.6
June 2	5:27	1084	−19.9	−1.8	Aug. 26	4:48	1041	−19.2	−1.8	" "	6:16	990	−10.7	−1.1
June 29	3:03	1037	−16.2	−1.6	" "	9:28	925	− 2.4	−0.3					
July 10	3:20	975	−17.3	−1.8	Oct. 8	0:55	957	−15.7	−1.7					
July 23	1:58	858	−14.5	−1.7	Oct. 31	4:37	983	−12.6	−1.3					

TABLE XXVIII.

DECREASE OF TEMPERATURE, IN DEGREES FAHRENHEIT PER HUNDRED METERS, AT DIFFERENT HOURS ON DAYS WITH CUMULUS CLOUDS.

Valley to Kite at 500 Meters. — May to August.

	A. M.	P. M.								
	11-12	12-1	1-2	2-3	3-4	4-5	5-6	6-7	7-8	9-10
	1.7	1.8	1.9	2.1	1.4?	1.3?	0.6?			+0.5
	1.7	2.1	2.1	1.8	1.9		2.0	1.9		
			1.8	1.9	1.8	1.4	1.9	1.2		
				1.8	1.7	1.9	1.2			
				2.1	2.2	2.0	1.8			
				2.1	2.1					
					1.9					
Means	1.7	2.0	1.9	2.0	1.9	1.8	1.7	1.6		

Valley to Kite at 500 Meters. — November to February.

	A. M.	P. M.								
	11-12	12-1	1-2	2-3	3-4	4-5	5-6	6-7	7-8	8-9
				1.6	1.8	2.1	1.2	1.0		
					2.0		1.6			
					1.7		0.9			
					1.8					
Means					1.8		1.2			

Valley to Kite at 1,000 Meters. — Year.

	A. M.	P. M.								
	11-12	12-1	1-2	2-3	3-4	4-5	5-6	6-7	7-8	8-9
		1.7	1.7		1.6	1.9	1.1	0.5		0.3
		1.7			1.8	1.8	1.8	1.4		
		2.0			1.7	1.3		1.1		
					1.8	1.6				
Means		1.8	1.7		1.7	1.7	1.5	1.0		0.3

NOTE. — A question mark (?) indicates observations made in 1895, when a weekly clock cylinder was used on the thermograph at the Valley Station. The figures thus marked are considered untrustworthy, and are not used in the means. The sign + indicates that the temperature was higher at the kites than at the ground.

A striking feature of Table XXVIII. is that the means show a maximum rate of change of temperature with change of altitude near the warmest part of the day, and a small rate of change after sunset. In the only observation after 9 P. M. at

500 meters, the sign was reversed, showing the air to be warmer at that altitude than at the Valley Station. The average rate appears to equal or to exceed slightly the adiabatic rate during the daytime, at least until 5 P. M.

Dr. Hann, in his well known treatise on Die Gesetze der Temperatur-Aenderungen in Aufsteigenden Luftströmungen, etc., computes the adiabatic rate of cooling in dry air to be 0°.009907 C. for each meter of ascent, and says: "Therefore the cooling of the ascending air amounts almost exactly to 1° C. for every 100 meters, and it remains the same from whatever level the ascent begins or whatever the initial temperature may be. On the other hand, a descending air stream becomes 1° C. warmer for each 100 meters." (Zeitschrift der Oesterreichischen Gesellschaft für Meteorologie, Vol. IX. p. 323.)

He shows that this rate is somewhat diminished by moisture in the air, and, as an example, computes that ascending air with an initial temperature of 30° C., a relative humidity of 60 per cent, and consequently a vapor tension of 18.9 mm., would cool at the rate of 0°.009751 C. for each meter of ascent, which is equivalent to a decrease of 1°.755 F. for each 100 meters of ascent. In Recent Advances in Meteorology (Report of the Chief Signal Officer, 1885, Part II.), Ferrel discusses the problem of the adiabatic rate in dry air. He computes the rate of change as 0°.00979 n for each meter of ascent or descent; in this result the factor n causes the rate to diminish slightly with latitude south of 45°, and also with altitude. Since the adiabatic rate in moist air is slightly less than in dry air, this computation would make the normal rate of cooling in moist but unsaturated air somewhat less than 1°.76 F. for each 100 meters of ascent, probably about 1°.74 F. Professors Abbe and Bigelow, who were consulted in regard to the formula, suggest an additional term due to the direct heating of the air by insolation after it leaves the ground. The absence of any appreciable diurnal period above 1,000 meters arising from the direct effect of insolation and radiation on the air, prove, I think, that this term is negligible.

Computation of the Heights of Clouds by Means of the Dew-Point.

Fifty-six years ago Espy pointed out the possibility of computing the altitude of the base of cumulus clouds from the difference in temperature between the air and the dew-point. He proved that his computation was approximately correct by sending up a kite into the base of the cloud, thus determining its altitude. (Espy's Philosophy of Storms, p. 75.)

It is of interest to compare the altitudes of the bases of clouds measured by kites at Blue Hill with the altitudes computed from the differences between the

air temperature and the dew-point, using the more exact determination of the adiabatic rate by Hann and Ferrel. Besides knowing the adiabatic rate, it is also necessary to know in these computations the rate of change of the dew-point with altitude when the air is expanding adiabatically. This rate of change Professor W. M. Davis gives as 0°.2 C. (0°.36 F.) for each 100 meters. (Elementary Meteorology, p. 163.) Hence 0°.0176 F. (the adiabatic rate of cooling for each meter of ascent given by Ferrel) less 0°.0036 F. (the fall of the dew-point for each meter), divided into the difference between the air temperature and the dew-point, ought to give, approximately, the altitude at which the air is cooled by expansion to the temperature of the dew-point and condensation into cloud particles begins. In this, the small corrections for latitude and moisture are neglected, and the formula becomes $\frac{\text{d. b.} - \text{d. p.}}{0.014}$ = altitude of base of cloud. In this d. b. is the temperature shown by the dry-bulb thermometer, and d. p. is the dew-point. This agrees with the formula in Davis's Elementary Meteorology (page 163), which is $(1.6 - 0.3) \times 300$ ft.

Table XXIX. gives the observed heights of clouds in meters as measured by kites, the heights computed by the preceding formula, and their differences.

Table XXX. shows these differences between the observed and the computed heights, classified according to the hours of the day and also according to the measured altitudes of the cloud. The altitudes in these tables are above the level of the top of Blue Hill, and not above the level of the Valley Station, as in the preceding tables.

In these tables not only cumulus, but also strato-cumulus, stratus, and nimbus, are included in the investigation, and the heights computed from the differences between the air temperature and the dew-point agree in a general way with the measured heights of all these different cloud forms.

When the differences between the observed and the computed heights are classified according to the hours of the day, as in Table XXX., the computed altitudes average lower than the observed altitudes until noon; between noon and 2 P. M., the two are nearly the same; and after 2 P. M., the computed exceed the observed heights by differences which rapidly increase as evening approaches. It is well known that the difference between the air temperature and the dew-point increases until the warmest part of the day, and then diminishes until the coldest; hence the best explanation of the observed facts is that the vapor from which the cloud is formed left the surface of the ground some time previously.

TABLE XXIX.

HEIGHTS OF CLOUDS MEASURED BY KITES COMPARED WITH HEIGHTS COMPUTED FROM THE DEW-POINT.

Date.	Hour.	Kind of Cloud.	Observed Height.	Computed Height.	Observed minus Computed.	Date.	Hour.	Kind of Cloud.	Observed Height.	Computed Height.	Observed minus Computed.
1896.			*meters.*	*meters.*	*meters.*	1896.			*meters.*	*meters.*	*meters.*
July 20	10:38 A	cu	661	686	− 25	Oct. 8	4:34 P	s cu	1344	985	+ 359
" "	1:43 P	"	809	842	− 33	" "	5:23 P	"	1370	857	+ 513
Aug. 31	10:54 A	"	1137	1214	− 77	Dec. 15	2:23 P	"	530	428	+ 102
Oct. 8	1:58 P	"	1178	1143	+ 35	1895.					
" "	2:05 P	"	1224	1136	+ 88	Nov. 23	11:30 A	f s	61	456	− 395
Nov. 17	3:31 P	"	1420	1113	+ 307	Dec. 9	9:49 A	s	138	164	− 26
Jan. 18	4:00 P	s cu	410	414	− 4	1896.					
May 6	9:40 A	"	190	207	− 17	May 22	8:30 A	s	107	00	+ 107
" "	9:47 A	"	198	249	− 51	" "	8:55 A	f s	175	00	+ 175
June 6	9:46 A	"	290	421	− 131	July 3	3:50 P	s	243	157	+ 86
" "	2:30 P	"	244	292	− 48	Oct. 31	9:20 A	"	282	456	− 174
" "	3:00 P	"	242	271	− 29	" "	9:25 A	"	354	464	− 110
" "	4:53 P	"	232	164	+ 68	Nov. 18	0:29 P	"	383	285	+ 98
July 22	2:33 P	"	425	514	− 89	" "	0:46 P	"	331	292	+ 39
" "	4:35 P	"	393	321	+ 72	1897.					
" "	5:18 P	"	339	207	+ 132	Jan. 2	11:55 A	"	321	342	− 21
Sept. 3	4:01 P	"	454	378	+ 76	" "	0:01 P	"	334	349	− 15
" "	4:15 P	"	361	342	+ 19	" "	1:00 P	"	324	342	− 16
Sept. 16	10:22 A	"	411	578	− 167	1896.					
" "	0:15 P	"	321	507	− 186	Jan. 18	10:50 A	N ✱°	197	200	− 3
" "	3:17 P	"	287	299	− 12	Feb. 13	2:15 P	N ◍°	30	00	+ 30
Sept. 17	2:52 P	"	660	456	+ 204	Feb. 18	2:45 P	f N ✱°	178	222	− 44
" "	3:00 P	"	610	450	+ 160	Mar. 11	11:56 A	f N ✱°	401	328	+ 73
" "	3:34 P	"	784	357	+ 427	June 15	9:10 A	N	165	143	+ 22
Sept. 19	3:53 P	"	245	242	+ 3	Aug. 22	4:12 P	N ◍°	1108	778	+ 330
Oct. 6	10:25 A	"	291	242	+ 49	Sept. 28	3:00 P	f N	260	157	+ 103
" "	11:26 A	"	476	364	+ 112	Oct. 5	10:38 A	N	297	285	+ 12
" "	11:45 A	"	333	235	+ 98	Oct. 29	9:10 A	N	312	214	+ 98
" "	0:42 P	"	422	292	+ 130	Nov. 24	10:01 A	N	340	285	+ 55
Oct. 8	2:39 P	"	1341	1143	+ 198	Nov. 28	8:25 A	N	235	157	+ 78
" "	3:01 P	"	1454	1143	+ 311	" "	1:50 P	N	277	228	+ 49
" "	3:34 P	"	1360	1100	+ 260	Dec. 9	9:28 A	f N	66	14	+ 52

In this table cu = cumulus, s cu = strato-cumulus, s = stratus, f s = fracto-stratus, N = nimbus, f N = fracto-nimbus, ✱° = light snow, ◍° = light rain.

In computing the heights in Table XXIX., the difference between the air temperature and the dew-point was taken in each case at the time of the measurement of the cloud heights, when, to be more exact, it should have been taken some time earlier, in order to get the conditions of the ascending air within which the cloud

TABLE XXX.

DIFFERENCES BETWEEN OBSERVED AND COMPUTED HEIGHTS OF CLOUDS, IN METERS.

	At Different Hours.								
	A. M.			P. M.					
	9.00 to 9.59.	10 00 to 10.59.	11.00 to 11.59.	12.00 to 0.59.	1.00 to 1.59.	2.00 to 2.59.	3.00 to 3 59.	4.00 to 4.59.	5.00 to 5.59.
	− 17	− 25	+112	−186	−33	+ 88	+307	− 4	+132
	− 51	− 77	+ 98	+130	+35	− 48	− 29	+ 68	+513
	−131	−167	−395	+ 98	+49	− 89	− 12	+ 72	
	− 26	+ 49	+ 73	+ 39	−16	+204	+160	+ 76	
	−174	− 3	− 21	− 15		+240	+427	+ 19	
	−110	+ 12				+198	+ 3	+359	
	+ 22	+ 55				+102	+311	+330	
	+ 98					+ 30	+260		
	+ 52					− 44	+ 86		
							+103		
Means	−37	−25	−27	+13	+9	+76	+162	+131	+323

At Different Altitudes.													
0 to 99.	100 to 199.	200 to 299.	300 to 399.	400 to 499.	500 to 599.	600 to 699.	700 to 799.	800 to 899.	900 to 999.	1000 to 1099.	1100 to 1199.	1200 to 1299.	1300 to 1399.
+ 30	−17	−131	−186	− 25	+102	+204		−33			−77	+88	+198
+ 52	−51	− 48	+ 98	− 89		− 25					+35		
−395	−26	− 29	−110	−167									
	− 3	− 12	+ 98	+112									
	−44	+ 49	+ 39	+130									
	+22	−174	− 21	+ 73									
		+ 12	− 15										
		+ 78	− 16										
		+ 49	+ 98										
			+ 55										
	−20	−23	+4	−11							+61		

was formed. In the morning the computed heights would have been lower, and in the afternoon higher, than those given; thus agreeing better in each case with the measured heights.

The mean difference between the observed and the computed altitude of the cloud between 9 A. M. and 11 A. M. is found to be 32 meters, the computed height being higher. In order to lower the mean computed heights by this amount, it is necessary to subtract 0°.6 F. from the difference between the air temperature and the dew-point at the time of the measurements of the clouds. The mean increase

of temperature found at Blue Hill between 9 and 11 A. M. is 3°.3 F.; while the mean change in the dew-point for the same interval is virtually zero. Therefore at this rate of increase it would be necessary to take the atmospheric conditions prevailing 22 minutes earlier in order to diminish the difference between the air temperature and the dew-point 0°.6 F. Now the mean height of the clouds from which the differences were taken is 337 meters. Supposing that the air rises this distance in 22 minutes, the rate of ascent would be 15 meters per minute, or about 0.3 meter per second. In order to correct the computed height to the observed height, about 10 meters must be subtracted for each 100 meters of the computed height. However, in the afternoon, in order to make the computed height, even as late as 5 P. M., agree with the observed height, it is necessary to use the temperature and the dew-point prevailing near the warmest part of the day. It is shown in some of the earlier investigations in this discussion (page 99) that the adiabatic rate of change of temperature with change of altitude ceases soon after the warmest part of the day, and it is safe to infer that cloud formation from local ascending currents ceases about this time in ordinary conditions, and that the clouds remaining later are slowly subsiding under the influence of gravity, and are dissipating, provided no other causes are active in their formation, as is the case with nimbus and stratus.

Applying no correction to the morning observations, and omitting all results after 3 P. M. for the reason just given, the differences between the measured and the computed heights of the clouds are classified in Table XXX. according to altitude, using successive intervals of 100 meters each. The results show that most of the clouds measured by the kites were low clouds, the position of maximum frequency being about 350 meters above the top of Blue Hill; or, in round numbers, about 500 meters above the Valley Station. The means at the foot of the table show that the measured heights were less than the computed heights at the lowest altitudes, and greater than the computed ones at the highest altitudes. This is because clouds were found at the lowest altitudes chiefly in the morning and at the highest altitudes in the afternoon, as shown by the following average heights, in meters: —

	A. M.				P. M.			
Hour	9.00 to 9.59	10.00 to 10.59	11.00 to 11.59	12.00 to 0.59	1.00 to 1.59	2.00 to 2.59	3.00 to 3.59	4.00 to 4.59
Mean altitude of cloud in meters	222	476	318	360	647	592	710	612

However, the chief interest is not in the means given in the table, in which the + and the — sign partly neutralize each other, but it is in the means of the differences without regard to sign. These are as follows: —

Altitude in meters	00 to 99	100 to 199	200 to 299	300 to 399	400 to 499	500 to 599	600 to 699	700 to 799	800 to 899	900 to 999	1000 to 1099	1100 to 1199	1200 to 1299	1300 to 1399
Mean of differences	27	62	74	113									99	
Per cent of altitude	18	18	19	25									8	

This shows that the mean error in computing the cloud heights by the formula given on page 123 is about 18 per cent for the low clouds, which were stratus, strato-cumulus, and nimbus. However, this also includes the errors in the measurements of the base of the clouds by the kites, so that the probable error of the determination of the cloud height by the formula presumably does not exceed about 10 per cent. Refinements by the use of the factors omitted from the formula, and by taking as a basis the conditions of the air when it left the ground, and not the conditions at the ground when the cloud was measured, will no doubt greatly improve this result. In the case of stratus and nimbus clouds, the air is probably ascending very obliquely, so that some correction may possibly be needed for change of latitude or of environment. For example, the air in which floats the nimbus cloud observed overhead may have ascended from the ground 50 kilometers distant from the station over which it is observed.

The mean error of the computed heights of the cumulus clouds which were found between 1,100 and 1,400 meters is considerably less, relatively, than that found for the lower clouds, because it averages only 8 per cent of the altitude. But this difference is a compound of the errors of measurement and of the errors in the computed heights; so that the probable error of any computed altitude by the formula described presumably does not exceed 5 or 6 per cent of the true height. The error of measurement includes not merely the error of determining the height of the kites, which is very small, but it includes also the error of determining when the kites enter the base of the clouds. This error may be considerable, because the kites in some cases rise between passing clouds, and higher than their bases, before the cloud is entered. When the distance above the base was short, it could not always be determined (owing to perspective) whether the kites entered the cloud at the base or slightly above it; especially if the bases were more or less irregular and indeterminate, as sometimes happened. The differences of level between the bases of adjoining clouds sometimes amounted apparently to as much as 1 per cent of the altitude.

Hence the conclusion drawn from this investigation is that the difference in temperature between the air and the dew-point furnishes an easy and fairly trustworthy

method of determining the heights of clouds below 1,500 meters. The probable error of any determination in the case of low clouds will be perhaps 100 meters. But if the computations of height are confined to the warmest part of the day (between 1 and 2 P. M.), the results at Blue Hill indicate that the mean error of a number of cases will be less than 2 per cent of the altitude, an accuracy equal to that of measurements by theodolites. This determination, however, is subject to the reservation that the clouds must be moving in approximately the same direction as the surface wind, otherwise the conditions may be very different at the cloud and at the ground. For example, if a sea-breeze is blowing at the ground, it would be impossible to compute the altitude of cumulus, which is seen at a distance, and which may be forming at the edge of the sea-breeze over a heated land surface.

Altitudes of the Kites when Electricity was First Noticed.

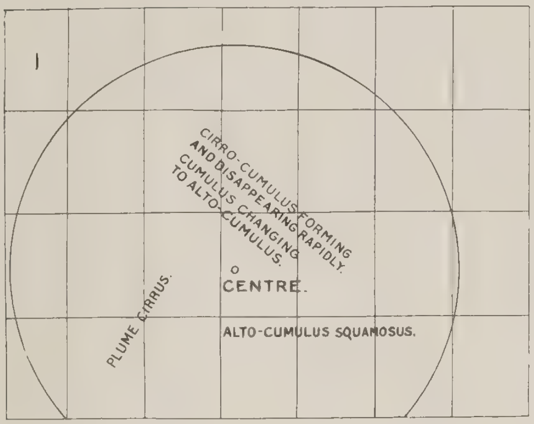
After the introduction of wire for a kite line, electric shocks were received from the wire, and sparks 2 to 5 mm. in length were occasionally seen when a conductor was brought near the wire. The wire was not insulated except by the wooden stand on which the reel was placed; but when the kites were at great altitudes, the electricity at times became so unpleasant that it was necessary to make a connection with the ground. The altitudes of the upper end of the kite line, when electrical effects were first noticed, were variable, and, to a certain extent, evidently dependent on the weather. Thus in snowstorms, electricity was much more active than in other weather. No ascents were made very near thunderstorms, except on May 11, 1896, when the kites were drawn down rapidly as a thunderstorm approached from the west, and on May 19, when the kites were sent up after the passage of a thunderstorm. In both cases the altitude was small, and only in the first case were strong shocks felt. The dates and altitudes at which strong electrical effects were noticed will be found in the Remarks following Tables XVII. and XVIII. Variations in the amount of wire on the reel, and changes in its insulation, no doubt affect the altitude at which electricity is noticeable. Therefore the altitudes cannot be taken as entirely trustworthy indications of the relation of electrical potential to weather conditions, although the electricity became much stronger in snowstorms and near thunderstorms, as previously mentioned. In the majority of cases, the altitude of the top of the line when electricity was first noticed was about 500 meters, and the potential increased with height.

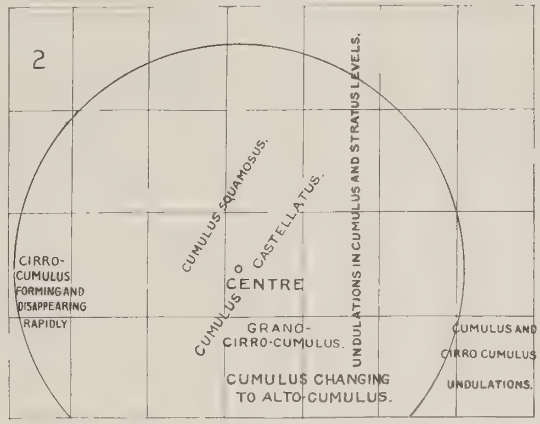
Mr. Fergusson and I are indebted to Mr. H. S. Mackintosh for a careful revision of our manuscripts.

END OF VOLUME XLII. PART I.

DISTRIBUTION OF SPECIAL CLOUD FORMS.

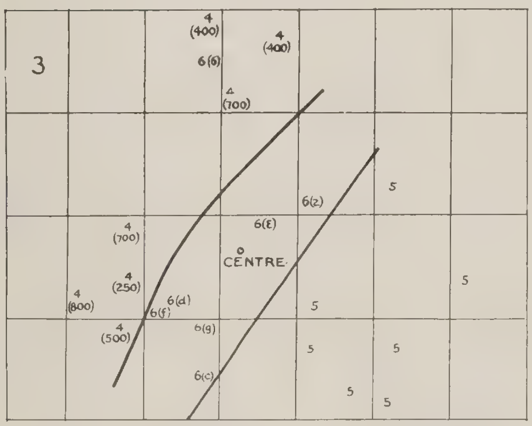
ANTI-CYCLONES. CYCLONES.

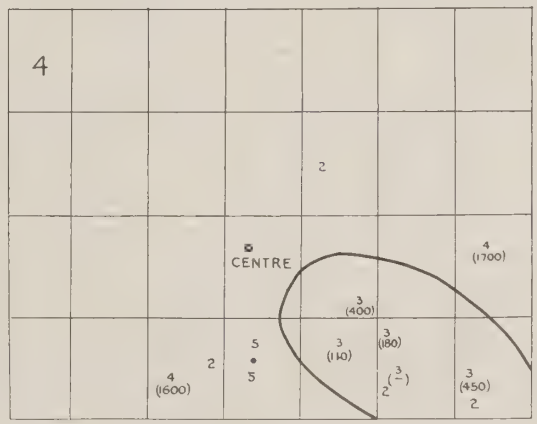




DISTRIBUTION OF TEMPERATURE TYPES.

ANTI-CYCLONES. CYCLONES.





DISTANCES.
0 800
KILOMETERS.

HARGRAVE KITES TRIED IN 1895.

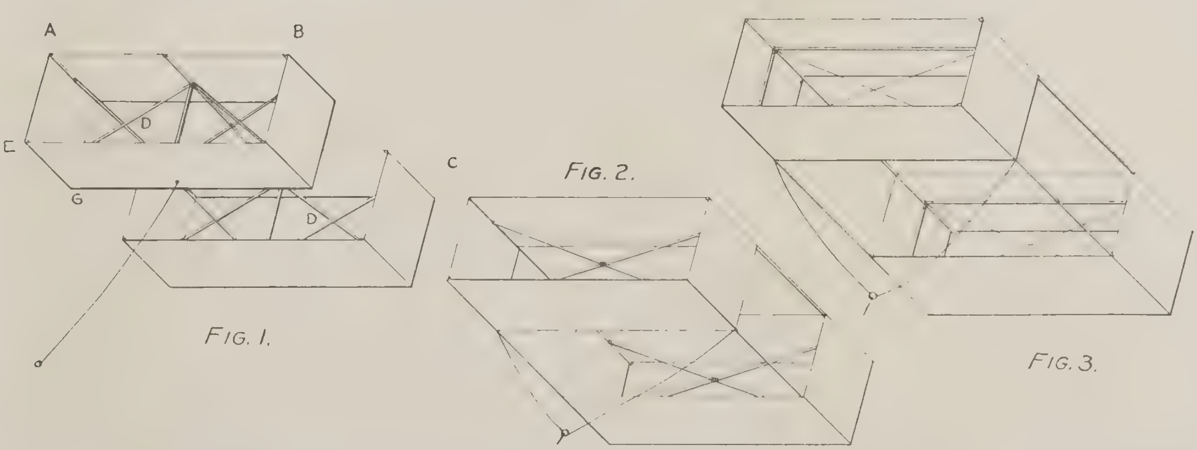


FIG. 1. FIG. 2. FIG. 3.

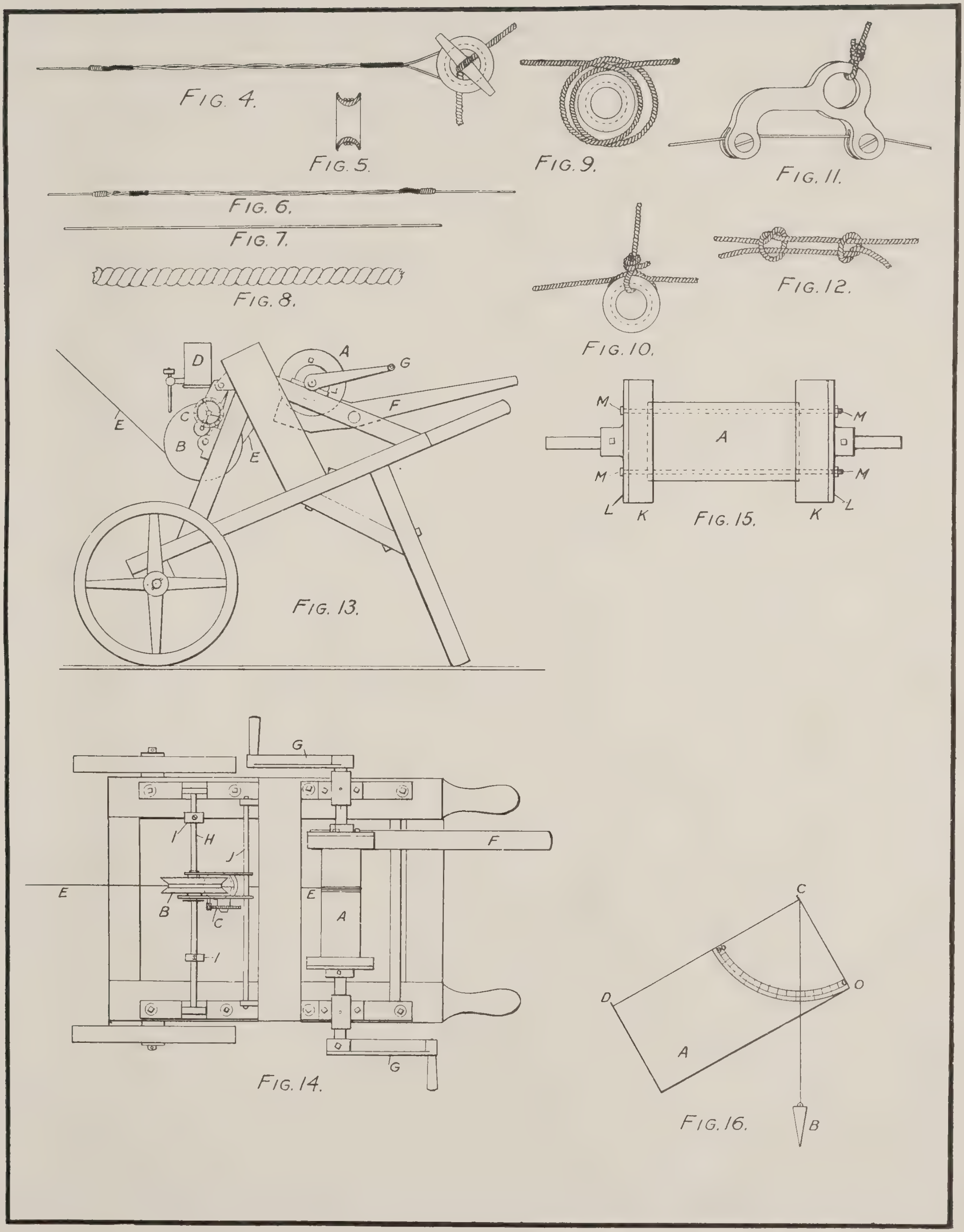


FIG. 4.
FIG. 5.
FIG. 6.
FIG. 7.
FIG. 8.
FIG. 9.
FIG. 10.
FIG. 11.
FIG. 12.
D
A
G
C
F
E
B
E
FIG. 13.
M
M
A
M
M
L
K
FIG. 15.
K
L
G
I
H
J
E
B
C
E
A
F
I
G
FIG. 14.
C
D
O
A
FIG. 16.
B

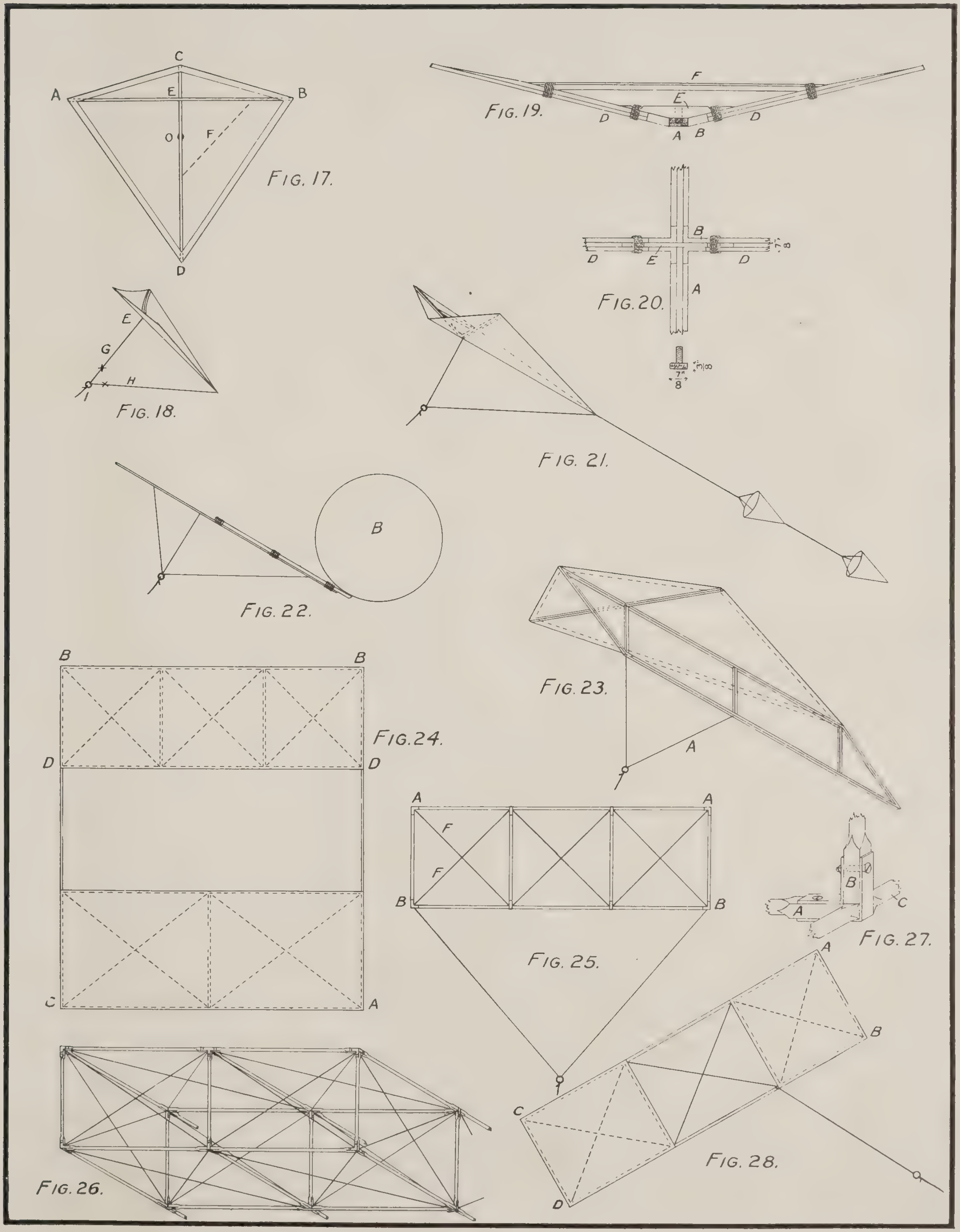


FIG. 17.
FIG. 18.
FIG. 19.
FIG. 20.
FIG. 21.
FIG. 22.
FIG. 23.
FIG. 24.
FIG. 25.
FIG. 26.
FIG. 27.
FIG. 28.

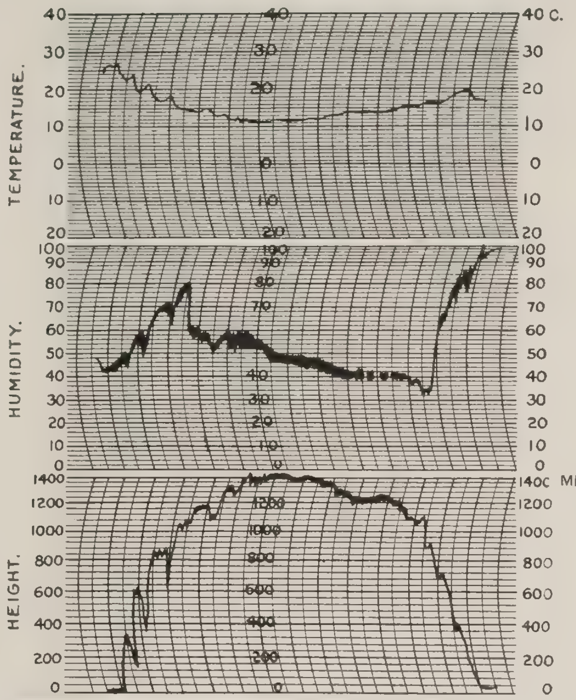


FIG. 29.

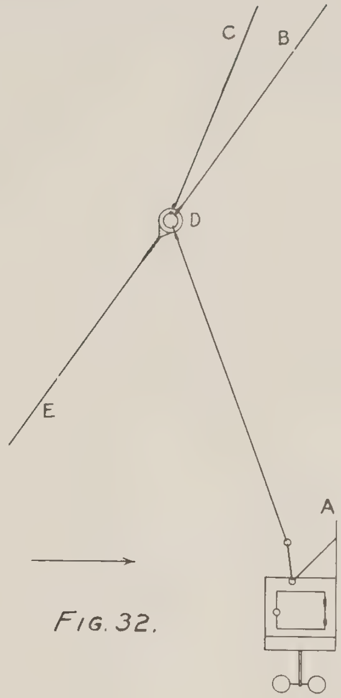


FIG. 32.

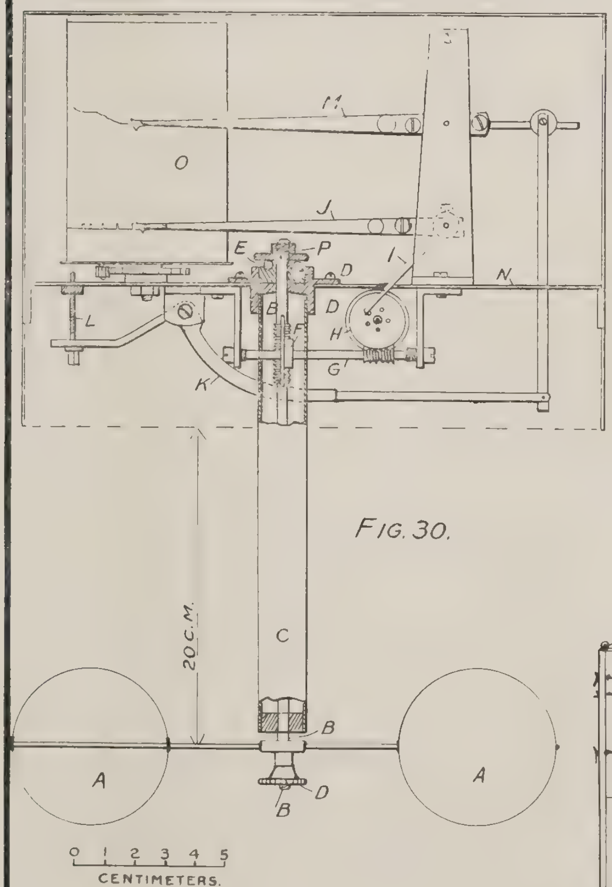


FIG. 30.

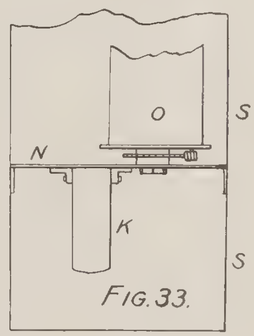


FIG. 33.

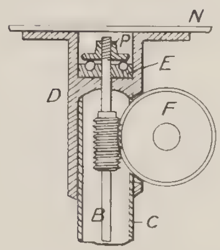


FIG. 31.

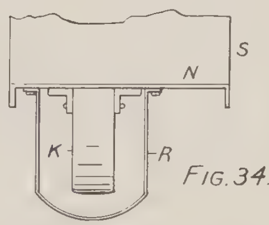


FIG. 34.

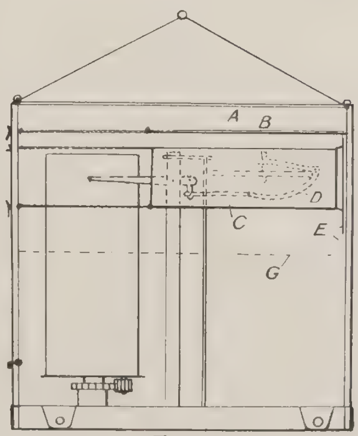


FIG. 35.

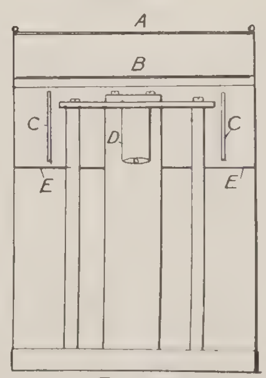
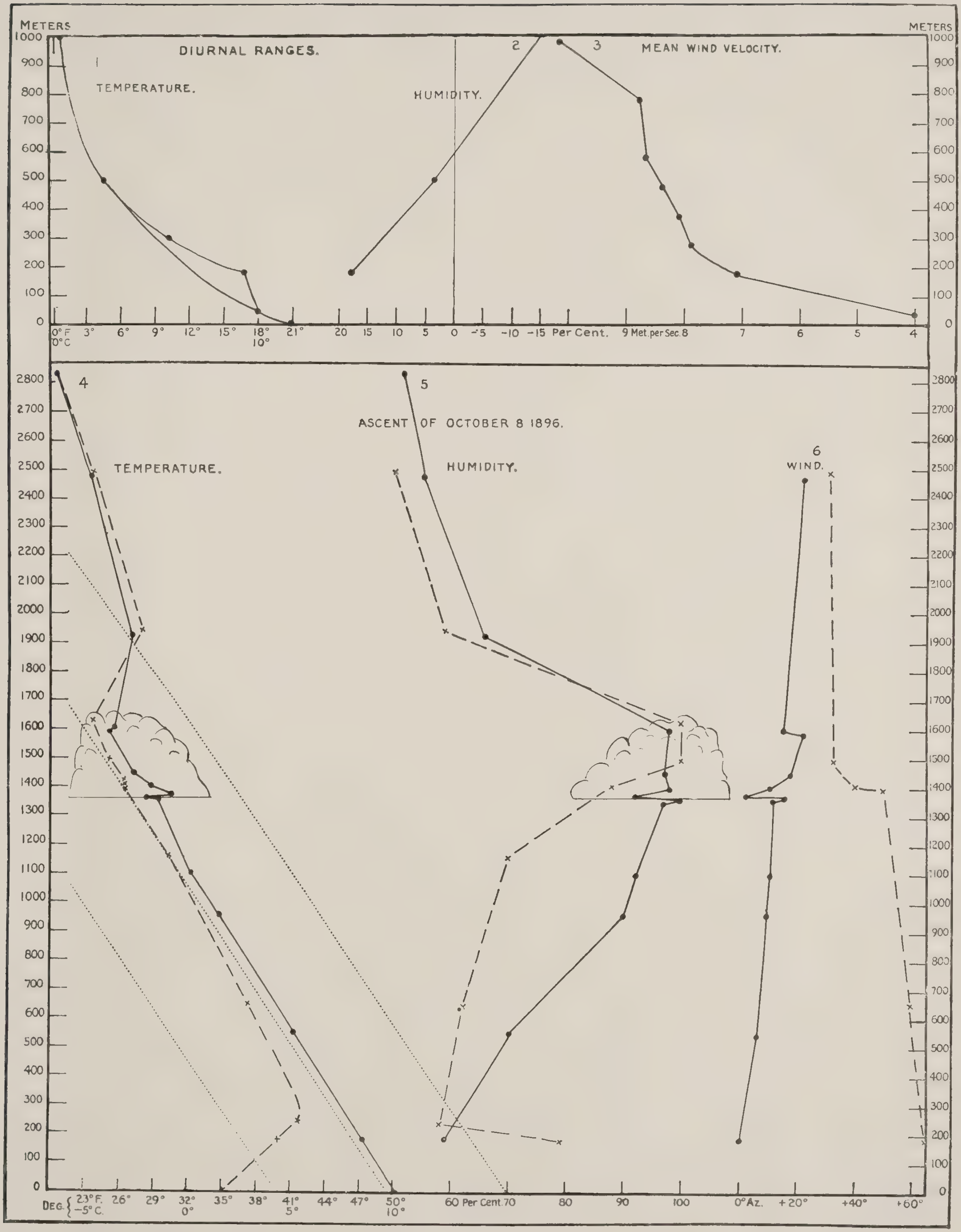
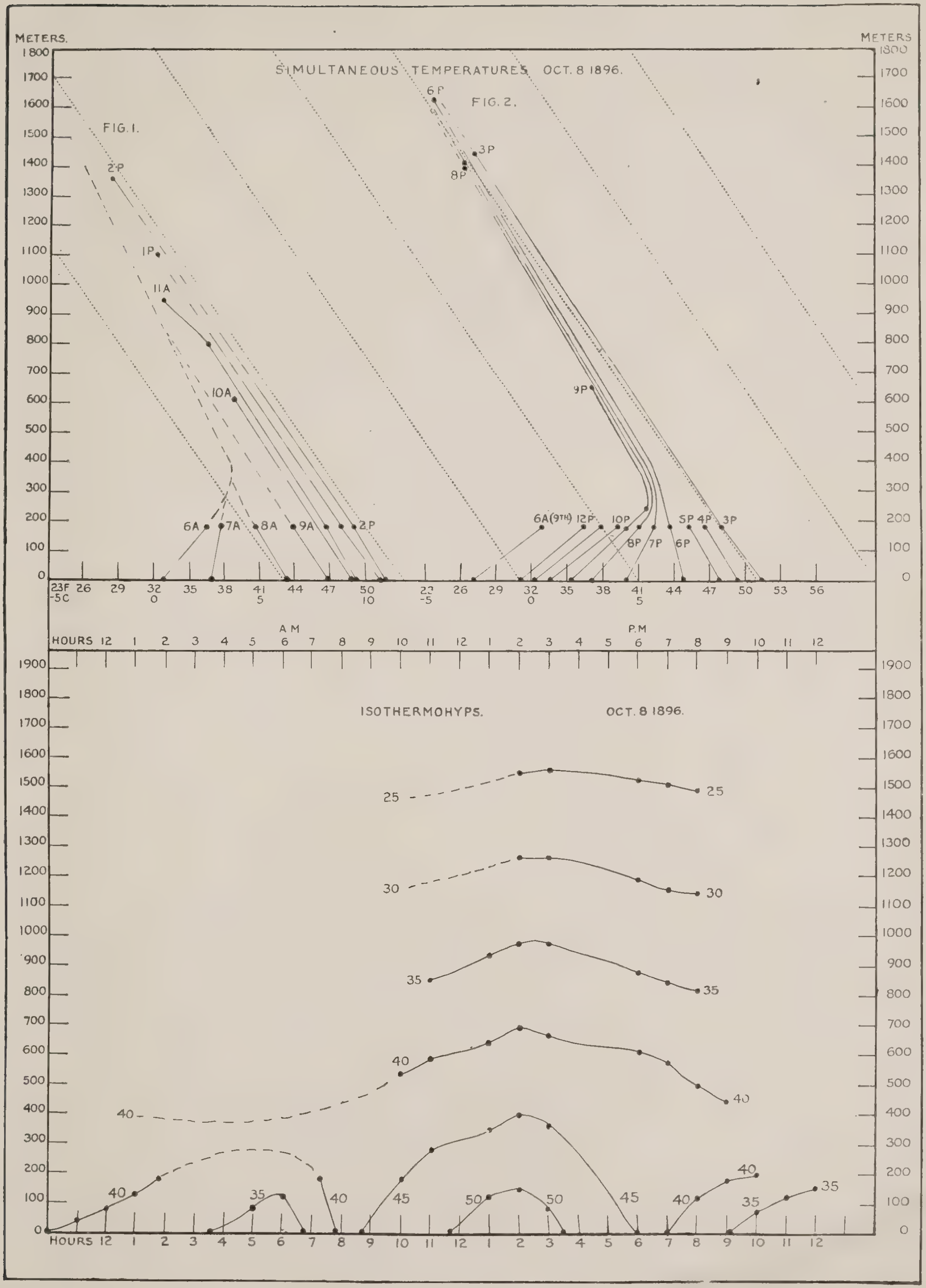


FIG. 36.


METERS
DIURNAL RANGES.
1 TEMPERATURE.
2 HUMIDITY.
3 MEAN WIND VELOCITY.
0°F 3° 6° 9° 12° 15° 18° 21°
0°C 10°
20 15 10 5 0 -5 -10 -15 Per Cent.
9 Met. per Sec. 8 7 6 5 4
4 TEMPERATURE.
5 ASCENT OF OCTOBER 8 1896.
HUMIDITY.
6 WIND.
DEG. 23°F. 26° 29° 32° 35° 38° 41° 44° 47° 50°
-5°C. 0° 5° 10°
60 Per Cent. 70 80 90 100
0° Az. +20° +40° +60°


SIMULTANEOUS TEMPERATURES OCT. 8 1896.
FIG. 1.
FIG. 2.
METERS
HOURS
A.M
P.M
ISOTHERMOHYPS. OCT. 8 1896.

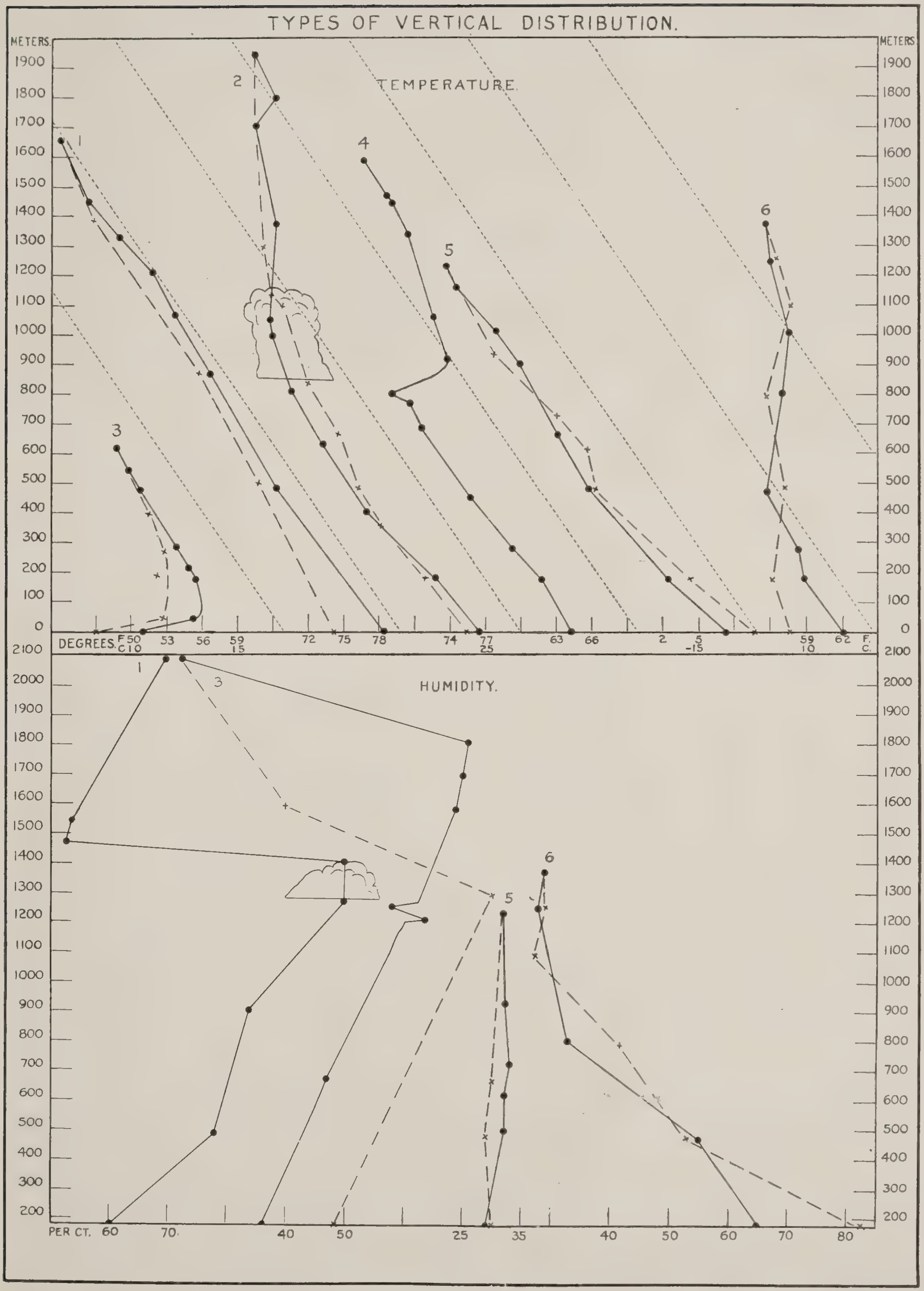
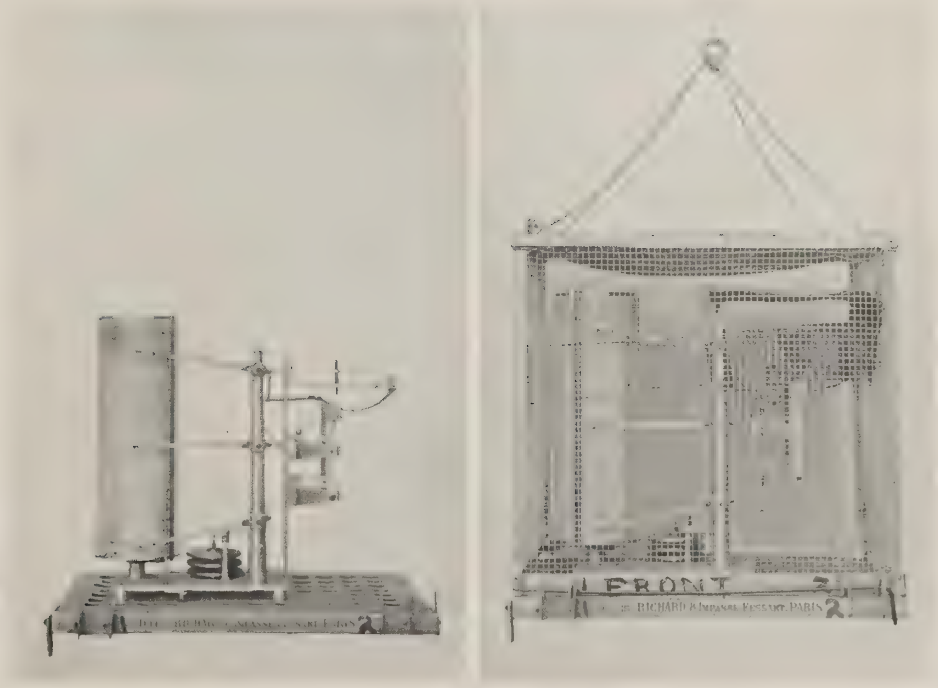

TYPES OF VERTICAL DISTRIBUTION.
TEMPERATURE.
HUMIDITY.
METERS.
DEGREES.
PER CT.

PLATE VIII.

EDDY KITE.

HARGRAVE KITE.

THERMOGRAPH USED IN 1894.
THE FIRST LIFTED BY A KITE.



RICHARD METEOROGRAPH.
EMPLOYED IN 1896-1897.